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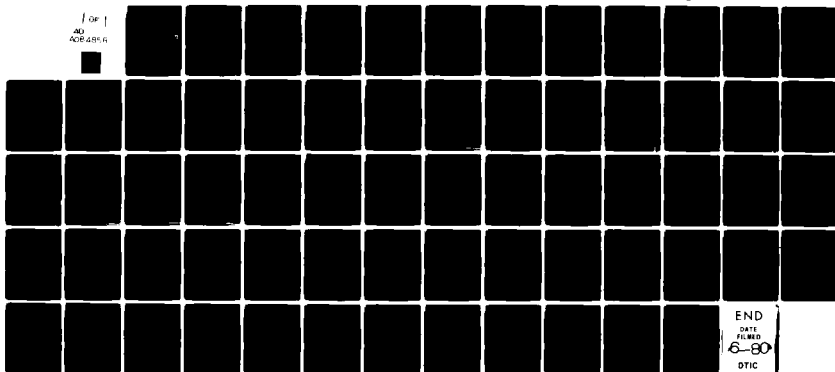
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COMPUTER SIMULATION OF AUXILIARY POWER SYSTEMS.(U)  
MAR 80 D J GURECKI  
AFAPL-TR-79-2118

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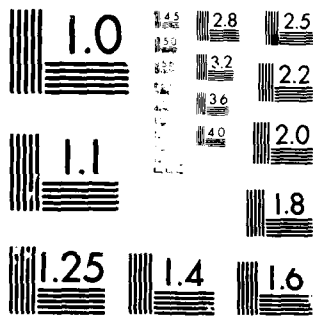
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COMPUTER SIMULATION OF AUXILIARY POWER SYSTEMS

AEROSPACE POWER DIVISION  
POWER SYSTEMS BRANCH

March 1980

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TECHNICAL REPORT AFAPL-TR-79-2118  
Final Report for ~~Period April 1979 - August 1979~~

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AIR FORCE AERO PROPULSION LABORATORY  
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES  
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This technical report has been reviewed and is approved for publication.



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FOR THE COMMANDER



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A digital computer program for the analysis of Auxiliary Power Units (APU's) has been developed. It analyzes the thermodynamics of each component, compressor, combustor, and turbine with regards to basic performance parameters and bleed leakage flows. On the first pass, the code solves for available horsepower from the APU on the basis of input component pressure ratio and efficiencies. On the second pass, the component performance is solved to satisfy the desired design shaft horsepower of the APU. This code is called APUCODE. It is a derivative of SMOTE (Simulation of Turbofan Engine), developed in AFAPL/TBC by Capt John S. McKinney, USAF, AFAPL-TR-67-125.		

# FOREWORD

This report describes work conducted within the Air Force Aero Propulsion Laboratory, Power Division, Power Systems Branch (POP-1), Wright-Patterson Air Force Base, Ohio. The work was accomplished under Project 3145, "Aerospace Power," Task 314501, "Dynamic Energy Conversion for Aerospace," Work Units 31450127, "Auxiliary Power Unit Simulation," and 31450142, "Computer Simulation of Auxiliary Power Systems," between July 1974 and November 1979.

This report was submitted by the author, 1Lt Daniel J. Gurecki, in November 1979. Previous project engineers were Capt John G. Grelick, and Richard E. Quigley. Final project engineer is 1Lt Daniel J. Gurecki.

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## SECTION I

### INTRODUCTION

The typical Auxiliary Power Unit (APU) is a small gas turbine, independent of the main engine, which supplies shaft horsepower and compressed air to start the main engine and run accessories as needed in the aircraft. APU designs are typically single-spool or single-spool with power turbine. The need for high power density in a confined space necessitates use of both axial and centrifugal designs in the compressors and turbines. Presently there exists a need to analyze APU's and aerodynamic torque converter configurations in AFAPL.

This report serves to document the previous modifications to the SMOTE program which have resulted in the APUCODE program. APUCODE simplifies the SMOTE program to analyze the basic single-spool gas generator while incorporating options peculiar to APU's. At present, APUCODE analyses only design-point conditions. In addition, numerous changes have been made to make input and output pages more readable.

This report is a user's manual for design-point APUCODE. It includes complete Fortran listing of the code and sample data cases. The code has been programmed in a straightforward manner for simplicity and ease of modification. Comment cards describe the major subdivisions of the main subroutine, APU, and flowcharts aid the understanding of the program logic.

## SECTION II

### PROGRAM DESCRIPTION

#### 1. APU IN GENERAL

APU is the main program subroutine in APUCODE. It controls the use of subroutines, sequences the logic of the calculations, and prints the output. The program logic follows the gas path through the APU from inlet to exhaust. Thermodynamic properties of the flow are computed at the inlet or exit of each component. Typical computing stations are shown in Figure 1 and defined in Table 1. Calculations are assumed to be adiabatic. The properties at downstream computing stations are calculated from mass-averaged upstream quantities, and the change in those quantities due to addition or extraction of shaft work and flow.

#### 2. SEQUENCE OF OPERATIONS IN APU

##### a. Inlet and Compressors

After printing the INPUT page, inlet conditions are computed from 1962 standard atmosphere. Inlet duct pressure loss is used to compute the total pressure at the compressor inlet. Throughout the program, at each computing station, subroutine THERMO provides calculation of gas properties. Work for the low and high pressure compressors is computed from input pressure ratios, efficiencies, and losses. If only one compressor exists, it will be computed as the High Pressure Compressor (HPC).

##### b. Bleed Flows from the High Pressure Compressor

Bleed flows for turbine cooling and accessory power are subtracted from the HPC inlet flow. The HPC bleed flow can be split into turbine inlet nozzle cooling, High Pressure Turbine (HPT) cooling, and Low Pressure Turbine (LPT) cooling. The remainder is bleed air which is lost from the APU flow and used to power the APU fuel pump, oil pump and other accessories. Each bleed flow is accounted for as a fraction of the HPC inlet flow and listed in the program output. Losses in the bleed ducting are used to arrive at the thermodynamic properties of the bleed flow when it enters the main flow to serve as turbine cooling air.

##### c. Combustor

The combustor calculates the properties at combustor exit of a mixture of air and standard JP-4 fuel. The combustor exit temperature,  $T_4$ , must be input. Fuel flow and fuel heating value are optional and will be calculated if not specified. The combustor calculation iterates to a final exit temperature using

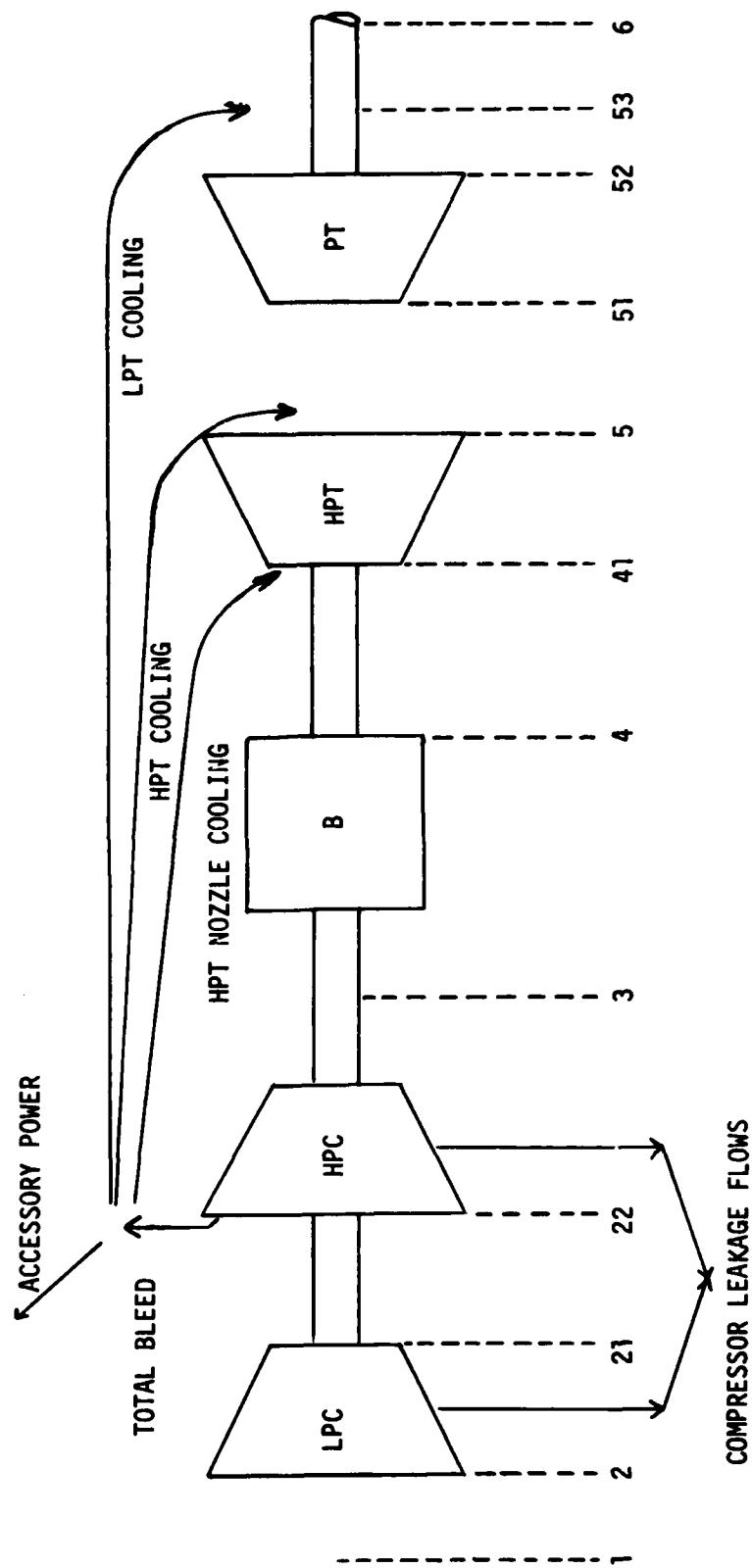


Figure 1 - Computing Station Location

TABLE 1  
COMPUTING STATION DESCRIPTION

STATION NUMBER

1	ambient conditions
2	low pressure compressor inlet
21	low pressure compressor discharge
22	high pressure compressor inlet
3	high pressure compressor discharge/burner inlet
4	main combustor discharge
41	high pressure turbine inlet plus inlet nozzle cooling
5	high pressure turbine discharge before cooling flow has been added
51	low pressure turbine inlet plus HPT cooling
52	low pressure turbine discharge before cooling flow has been added
53	low pressure turbine discharge including LPT cooling
6	exhaust duct exit

the Air Force Quadratic Interpolation Routine (AFQUIR). If the calculation fails to converge, a message is printed to that effect.

d. Turbines

There are three choices for the turbine configuration, see Figure 2: 1) a one-stage turbine, 2) a two-stage turbine, or 3) a one-stage turbine followed by a free turbine. The program makes two passes during each case: the first employs the pressure ratios and efficiencies as input to calculate the shaft work extracted from the APU; the second pass calculates the turbine pressure ratios necessary to provide the design APU shaft horsepower. At the end of the first pass, the output page is printed and control is transferred back to the combustor calculation. With compressors unchanged, the program continues on the second pass, and prints the output for the second pass.

(1) Turbine Overexpansion

If, on the first pass, the last turbine lowers the turbine exit pressure to less than atmospheric, an error is printed indicating overexpansion and the turbine exit pressure is set equal to atmospheric. Then, on the second pass, pressure ratio in the last turbine is recomputed based on expansion to atmospheric turbine exit pressure.

(2) Turbine Cooling

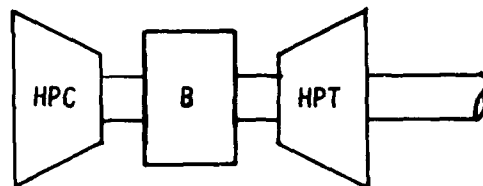
Before output is printed, cooling air modifies the first turbine inlet nozzles and each turbine exit. It is assumed that the cooling air injected into the turbine flow does no useful work, thus cooling air is added to the flow computation after the appropriate turbine exit station. It is then assumed to mix completely with the main flow and thus perform useful work in the downstream turbine.

(3) Exit Velocity

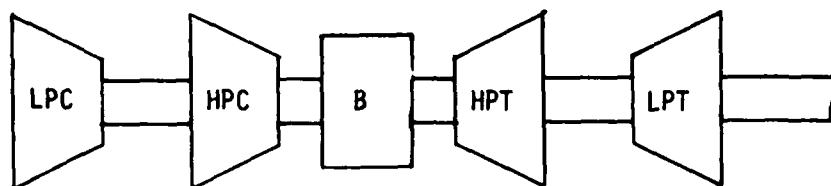
Flow velocity is computed at the last turbine exit based on the change in enthalpy from turbine exit to ambient conditions. Thrust and SFC are computed from this velocity. On the first pass, when turbine overexpansion occurs, this enthalpy change will be negative; hence, the exit velocity calculation will be invalid. This velocity and all values dependent on it will be printed out as "I."

(4) Peculiarities in the Case of One Turbine Followed by a Power Turbine

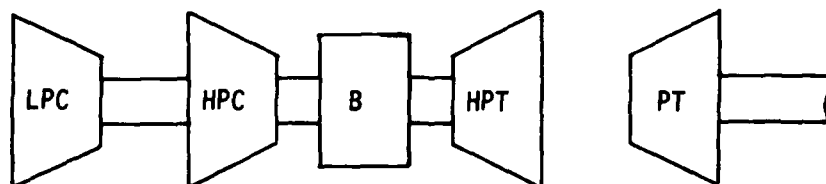
Because the power turbine rotates a shaft separate from the compressor-turbine shaft, the power turbine requires special attention. The power derived from the main turbine must be exactly equal to the power required by the compressors



1 STAGE COMPRESSOR 1 STAGE TURBINE CONFIGURATION



2 STAGE COMPRESSOR 2 STAGE TURBINE CONFIGURATION



2 STAGE COMPRESSOR 1 STAGE TURBINE WITH POWER TURBINE  
CONFIGURATION

Figure 2 - Possible APU Configurations

and the accessories. Thus, on the first pass, if the input main turbine pressure ratio results in this requirement not being satisfied, the correct pressure ratio of the main turbine is calculated. For this reason, the first pass output pressure ratio for the main turbine may not be that which was input.

Continuing in the first pass, the power turbine work is calculated from the input pressure ratio and printed out. In the second pass, the main turbine is unchanged, and the power turbine pressure ratio is recalculated to provide the design shaft horsepower.

### 3. QUADRATIC INTERPOLATION ROUTINE

Throughout the program there are many small loops (for example, thermodynamic iterations and table lookup) which require convergence. Trial-and-error methods and linear interpolations can be time-consuming, especially when a tight tolerance is necessary; therefore, a general interpolation routine called AFQUIR was developed.

#### a. Variables

This routine requires a dummy array dimensioned for nine locations. The other input variables are the independent and the dependent variables, the answer or value which the dependent variable is to converge upon, the number of tries at convergence, the tolerance, and a variable called DIR.

#### b. The DIR

The DIR is either set or calculated in the calling program. It is an initial guess at the direction and percentage change applied to the first value of the independent variable. If not enough is known to calculate a DIR, an arbitrary value may be set. This should not affect the final result but may increase the number of tries at convergence.

#### c. The Logic

The DIR, thus, establishes the second value of the independent variable. This value is used in the calling program to determine a corresponding second value of the dependent variable. AFQUIR is called a second time with these two sets of values. A linear interpolation results in a third value of the independent variable. AFQUIR is then called a third time with all three pairs of independent and dependent variables and a quadratic interpolation is made. The values of these three pairs of variables are stored in the dummy array and, henceforth, quadratic interpolations are made using the three sets which give values closest to the answer. Values farthest from the answer are lost.

#### d. Safeguards

Various safeguards are built into AFQUIR which either return the interpolation method to the initial guess or linear interpolation if the roots of the quadratic become complex. Complex roots are encountered if the quadratic does not intercept the answer, if the value of the independent variable differs radically from previous values, or if two pairs of independent and dependent variables are identical. It is also possible to preload the dummy array and to start directly at the linear or quadratic interpolations if desired.

#### e. Summary

In summary, AFQUIR is a completely flexible routine which performs quadratic interpolation for quick convergence of general functions. (SMOTE manual, reference no. 1, pages 11 and 12).

### 4. THERMODYNAMIC PROPERTIES SUBROUTINES

#### a. THERMO and PROCOM

Two subroutines are used to calculate thermodynamic properties of the flow at each computing station. They are PROCOM, which calculates gas properties for either air or fuel-air mixture, and THERMO, which calls PROCOM and calculates more complex properties. These subroutines are fairly simple and are listed with the rest of the code in Appendix B.

#### b. Use

The use of PROCOM is straightforward, but THERMO may be used in several ways. If pressure and enthalpy are input, total temperature is calculated. If pressure and temperature are supplied, enthalpy is calculated. Fuel-to-air ratio may also be input and taken into account in the property computations. These options are set by the programmer and are not available as options to the user from the input deck.

## SECTION III

### INPUT DESCRIPTION

#### 1. GENERAL

Subroutine APU is the main subroutine of APUCODE. Its logic is straightforward and is described at major subdivisions by comment cards. At the beginning of the code listing, the comment cards list brief descriptions of the program variables. The complete set of input variables need not be input for any one case. Variables not input are set equal to their default values as listed in Section III.6. Those parameters which are input override the default values.

#### 2. CARD FORMAT

All of the data cards must start in Column 2 or beyond. To start a data case, punch \$INPUT in Columns 2-7 then skip a space and continue by punching the input parameter names, followed by an "equals" sign and the appropriate numerical value. Values can be input up to column 72 inclusively. There is no limit to the number of cards in a data case. Finish the data case by punching a \$-sign immediately following the last value in that data case. The program executes the data case and returns to read the next case. The program will use values from the preceding point unless specifically changed in the data case that follows. See example A, Setup of APUCODE Deck, in Appendix A. To terminate a string of data cases, the last data case should be: \$INPUT IEND = 1\$.

#### 3. TITLE CARD

If specified, a title will be printed at the top of each case. To read a title card, set ITITLE = 1 in the NAMELIST data to which the title applies. The program then reads Columns 1-66 of the first card following that data case as the title. Since the program automatically sets ITITLE = 0 after a title has been read, ITITLE has to be set = 1 only when a new title is desired.

#### 4. ESTIMATES FOR ONE CASE

To compile (CP time) = 7.2 sec.

Input/Output time (IO) = 23 sec.

Line Estimate = 255 lines per case, or 3 computer pages

#### 5. SUBROUTINE DESCRIPTION AND PROGRAMMER OPTIONS

a. ATMOS (ALTP, T1, P1) - Computes temperature and pressure of the 1962 U. S. standard atmosphere up to 90 kilometers.

b. PROCOM (FAR, T1, CS, AKEX, CP, R, PHI, H) - Calculates thermodynamic gas properties for either air, or a fuel-air mixture based on JP-4.

c. THERMO (P, H, T, SOUT, AM, CP, GA, L, FAR, K) - Calculates thermodynamic conditions based on PROCOM. If K=1, P, FAR, and H are input; if K=0, T, FAR, and P are input.

d. COMB (PIN, T4, HIN, ETAB, DPB, POUT, HOUT, SOUT, FAR, HV) - Computes stoichiometric temperature in combustor if heating value for fuel and fuel flow are not input.

e. COMB2 (PIN, T4, HIN, ETAB, DPB, POUT, HOUT, SOUT, FAR, HV) - Similar to COMB. Used when fuel heating value is not input but fuel flow is input.

f. AFQUIR (X, AIND, DEPEND, ANS, AJ, TOL, DIR, ANEW, ICON) - General quadratic interpolation routine. All parameters explained in computer listing, see Appendix B.

NOTE: Parameters which are input to the subroutine are underlined.

## 6. INPUT DESCRIPTION

The following list describes all possible input parameters and, in parenthesis, their default values if they are omitted:

- ALTP - ALTITUDE IN FEET (0.0)
- DELTAMB - CHANGE IN AMBIENT TEMPERATURE FROM 1962 ATMOSPHERE (0.0)
- DELPAMB - CHANGE IN AMBIENT PRESSURE FROM 1962 PRESSURE (0.0)
- DPBLEED - BLEED DUCT PRESSURE LOSS (0.0)
- DPB - MAIN COMBUSTOR PRESSURE LOSS  $(P_3 - P_4)/P_3$  (0.0)
- DPC - INTERCOMPRESSOR PRESSURE LOSS  $(P_{22L} - P_{22})/P_{22L}$  (0.0)
- DPD - INLET DUCT PRESSURE LOSS (0.0)
- DPT - INTERTURBINE PRESSURE LOSS  $(P_5 - P_{51})/P_5$  (0.0)
- ETALPC - LP COMPRESSOR EFFICIENCY (1.0)
- ETAHPC - HP COMPRESSOR EFFICIENCY (1.0)
- ETAB - MAIN COMBUSTION EFFICIENCY (1.0)
- ETAHPT - HP TURBINE EFFICIENCY (1.0)
- ELALPT - LP TURBINE EFFICIENCY (1.0)
- ETAM - MECHANICAL EFFICIENCY (1.0)
- \* HV - MAIN COMBUSTOR FUEL HEATING VALUE AT T4 FOR JP-4  
(Optional. If omitted, it is calculated by the combustor calculation.)
- HPDS - DESIGN SHAFT POWER (0.0)
- HCSL - HPC SEAL LEAKAGE/HPC FLOW (0.0)
- IEND - 0 A DATA CASE FOLLOWS  
1 THIS IS THE LAST CASE (0)

ITITLE - 0 NO TITLE CARD WILL BE INPUT  
           1 TITLE CARD FOLLOWS THE DATA CASE (0)  
 LCSL - LPC SEAL LEAKAGE/LPC FLOW (0.0)  
 M - NUMBER OF TURBINE STAGES (no default)  
       = 1, ONE TURBINE APU DESCRIBED BY HPC INPUT  
       = 2, TWO TURBINE APU  
       = 4, ONE TURBINE DESCRIBED BY THE HPT INPUT AND ONE  
           POWER TURBINE DESCRIBED BY LPT INPUT  
 N - NUMBER OF COMPRESSOR STAGES (no default)  
       = 1, ONE COMPRESSOR STAGE DESCRIBED BY HPC INPUT  
       = 2, TWO COMPRESSOR STAGES  
 PRES - A MULTIPLIER ON PRESSURE VALUES FOR OUTPUT (1.0)  
       = 14.7, PRESSURES ARE IN PSI  
       = 1.0, PRESSURES ARE IN ATMOSPHERES  
 \* PRHPT - HP TURBINE PRESSURE RATIO (1.0)  
 \* PRLPT - LP TURBINE PRESSURE RATIO (1.0)  
 PCBLT4 - HP TURBINE INLET NOZZLE COOLING FLOW/HP COMPRESSOR INLET FLOW (0.0)  
 PCBLHP - HP TURBINE EXIT COOLING FLOW/HP COMPRESSOR INLET FLOW (0.0)  
 PCBLLP - LP TURBINE EXIT COOLING FLOW/HP COMPRESSOR INLET FLOW (0.0)  
 PRLPC - LP COMPRESSOR PRESSURE RATIO (1.0)  
 PRHPC - HP COMPRESSOR PRESSURE RATIO (1.0)  
 \* T4 - COMBUSTOR DISCHARGE TEMPERATURE (DEGREE RANKINE) (must be input,  
       no default)  
 WAENG - TOTAL ENGINE INLET AIRFLOW (1.0)  
 WF4DS - DESIGN FUEL FLOW (LB/HR) (if omitted, it will be calculated in  
       combustor calculations)

The program recalculates those parameters preceded by an asterisk. For this reason,  
 they must be input for each case if the user desires to keep them the same for each  
 case.

## SECTION IV

### OUTPUT DESCRIPTION

#### 1. REGULAR OUTPUT

Output for the three typical APU configurations are presented in Example Cases A, B, and C of the Appendix A. All descriptors on the printed output are designed to be self-explanatory.

##### a. Two Compressor - One Turbine APU

Example A shows an APU with two compressor stages and one turbine stage. Fuel flow and heating value are input. Pass 1 output shows that using the input parameters, the shaft horsepower obtained exceeds the desired design shaft horsepower. Pass 2 recalculates the pressure ratio of the turbine to satisfy the design shaft horsepower.

##### b. Two Turbine APU

If two turbine stages had been used, the program would have recomputed both HPT and LPT pressure ratios to obtain the design horsepower by preserving the work-split in the turbines as it was in Pass 1.

##### c. Example B

Example B illustrates the calculation of fuel heating value when fuel flow is input.

##### d. Power Turbine APU

Example C exhibits a power turbine configuration with fuel heating value input and fuel flow calculated. The input HPT pressure ratio was deficient so HPT pressure ratio was recalculated on Pass 1. With the input power turbine pressure ratio, overexpansion occurred. Exit velocity and its dependent parameters were computed as being indefinite errors and printed as "I." Pass 2 remedied the problem by recalculating power turbine pressure ratio to achieve design shaft horsepower.

#### 2. DIAGNOSTICS

Input errors will be indicated for each component when parameters are not logical. For compressors and turbines, execution stops when an input pressure ratio is less than 1.0 or an efficiency is greater than 1.0. For the combustor, execution stops when input combustor exit temperature or fuel flow is equal to or less than zero, or when combustor efficiency is greater than 1.0.

a. PROCOM Diagnostics

Subroutine PROCOM generates diagnostics in four cases: 1) when fuel-air ratio is above 0.067623, 2) fuel-air ratio is below zero, 3) the temperature input to PROCOM is below 300°R, or 4) the temperature input to PROCOM is above 4000°R.

b. THERMO Diagnostics

Subroutine THERMO halts execution after 15 iterations, if the value of enthalpy is not within a tolerance of 0.001 percent of the previous enthalpy guess.

c. Combustor Diagnostics

Subroutine COMB and COMB2 both print a message indicating lack of convergence of stoichiometric temperature. This message is a direct result of failure in subroutine AFQUIR. If after 15 iterations the solution to the quadratic equation for stoichiometric temperature has not been found, execution stops.

APPENDIX A  
EXAMPLE CASES

INPUT CARDS FOR EXAMPLE CASE A

\$INPUT ALTP=0., DELTAMB=71., PRES=14.696, WAENG=2.485346, ETAB=.995,  
DPC=.01, PRLPC=1.794, PRHPC=6.0, LCSL=0.0, HCSL=.02, ETALPC=.78, DPB=.07,  
ETALPT=.870, T4=2559.67, DPT=0.0, M=2, N=2, WF4DS=0., ETAHPC=.746,  
HPACC=9.5, PRLPT=9.418, HPDS=200., HV=18400., ITITLE=1, DPIN=.04,  
ETAM=.98, ETAHPT=.8, PRHPT=1.5, DPBLEED=.014\$  
SAMPLE DATA FOR APU

SAMPLE DATA FOR APU

\*\*\*INPUT VALUES\*\*\*

ALTITUDE (FT) = 0.  
 PRESSURE (PSI) = 14.696  
 DELTA TEMP FROM 1962 ATMOS = 71.00000  
  
 BEGIN INDICATOR = 1  
 END INDICATOR = 0  
  
 NO OF COMPRESSOR STAGES = 2  
 NO OF TURBINE STAGES = 1  
  
 FLOW = 2.48535  
 MECH EFF = .98000  
 HPACC EXTRACTED FOR ACCESS = 9.50  
 DESIGN SHAFT POWER = 165.0000  
  
 INLET DUCT PRESS LOSS = .04  
 LPC PRESS RATIO = 1.794  
 LPC EFF = .78000  
 LPC SEAL LEAKAGE = 0.0  
 LPC BLEED, TO BE USED LATER  
  
 INTER-COMP PRESS LOSS = .01  
 BLEED DUCT PRESS LOSS = .014  
  
 HPC PRESS RATIO = 6.000  
 HPC EFF = .74600  
 HPC SEAL LEAKAGE = .02  
  
 MAIN COMB PRESS LOSS = .07000  
 MAIN COMBUSTION EFF = .99500  
 DESIGN FUEL FLOW (LB/HR) = 150.00  
 MAIN COMB FUEL HEATING VALUE AT T4 FOR JP4 = 18400.  
 COMB DISCHARGE TEMP (DEGREE RANKINE) = 2559.67  
 HPT INLET NO2 COOLING/HPC INLET FLOW = 0.00000  
  
 HPT PRESS RATIO = 1.000  
 HPT EFF = .80  
 TURB COOLING/HPC INLET FLOW = 0.00000  
  
 INTER TURB PRESS LOSS (P5-P51)/P5 = 0.00  
  
 LPT PRESS RATIO = 9.418  
 LPT EFF = .87000  
 EXHAUST DUCT PRESS LOSS (P53-P1)/P53 = 0.0  
 LPT COOLING/HPC INLET FLOW = .01000

Example A - 2 Compressor Stages, 1 Turbine Stage

\*\*\*OUTPUT VALUES\*\*\*

STATION	PRESSURE-PSI	TEMP-DEG.F	ENTHALPY	FLOW	COR FLOW	DELTA	THEIA	FUEL/AIR	EFF	PRESS RATIO	DEL P
AMBIENT	14.696	130.00	140.93			1.000	1.137				
LP COMP INLET	14.108	130.00	140.93	2.485	2.760	.960	1.137		.78000	1.794	.04000
LP COMP EXIT	25.310	266.94	173.90	2.485	1.708	1.722	1.401				.01000
HP COMP INLET	25.057	266.94	173.90	2.485	1.725	1.705	1.401		.74600	6.000	
HP COMP EXIT/											
BURNER INLET	150.342	890.51	329.82	2.388	.377	10.230	2.603			10.656	
BURNER EXIT	139.818	2100.00	678.40	2.430	.567	9.514	4.935	.01745	.99500		.07000
TURB INLET	139.818	2100.01	678.40	2.430	.567	9.514	4.935	.01745	.87000	9.418	
TURB EXIT	14.846	1169.51	411.03	2.430	4.263	1.010	3.141	.01745			
TURB EXIT											
PLUS COOLING	14.846	1166.81	410.21	2.455	4.303	1.010	3.136	.01727			.01009
EXHT/STATIC COND	14.696	1166.81	410.21	2.455	4.347	1.000	3.136	.01727			

ALTITUDE (FT) = 0.  
 SPEED OF SOUND = 1190.44  
 DELTA TEMP FROM 1962 ATMOS = 71.00  
 DELTA PRESS FROM 1962 PRESS = 0.00

NO OF COMP STAGES = 2  
 NO OF TURB STAGES = 1

DESIGN SHAFT HP = 155.0000  
 SHP EXTRACTED = 254.98212  
 SHP EXTRACTED, COR FOR SL = 271.875  
 SHP EXTRACTED, COR FOR MECH EFF = 240.57248  
 HP EXTRACTED FOR ACCESSORIES = 9.500  
 HP NEEDED FOR LPC = 115.943  
 HP NEEDED FOR MPC = 548.26281

CALCULATED FUEL FLOW = 150.0000  
 FUEL FLOW COEF = 7.09711  
 MAIN COMB FUEL HEATING VALUE AT T4 FOR JPA = 18400.0

WORK OF LPC (BTU/LB) = 32.973  
 LPC SEAL LEAKAGE FLOW FRACTION = 0.00000

WORK OF MPC (BTU/LB) = 155.919  
 MPC SEAL LEAKAGE FLOW FRACTION = .02000

MPT WORK PERCENT = 0.000  
 HORSEPOWER OF MPT = 144.22645

LPT WORK PERCENT = 1.000  
 HORSEPOWER OF LPT = 919.18782

NET THRUST = 17.37298  
 GROSS THRUST = 17.37298  
 NET THRUST/ENGINE AIRFLOW = 6.99017  
 THERMAL EFF = .23504  
 EXHAUST EXIT VELOCITY = 227.708  
 ENGINE UNINSTALLED SFC (LB FUEL/HR-HP) = .6235

STATION	PRESSURE-PSI	TEMP-DEG.F	ENTHALPY	FLOW	COR FLOW	DELTA	THERM	FUEL/AIR	EFF	PRESS RATIO	DEL P
AMBIENT	14.696	130.00	140.93			1.000	1.137				
LP COMP INLET	14.108	130.00	140.93	2.485	2.760	.960	1.137		.78000	1.794	.04000
LP COMP EXIT	25.310	266.94	173.40	2.485	1.708	1.722	1.401				.01000
MP COMP INLET	25.057	266.94	173.40	2.485	1.725	1.705	1.401		.74600	6.000	
MPACOMP EXIT											
BURNER INLET	150.342	890.51	329.82	2.388	.377	10.230	2.603			10.656	
BURNER EXIT	139.818	2100.00	678.40	2.430	.567	9.514	4.935	.01745	.99500		.07000
TURB INLET	139.818	2100.01	678.40	2.430	.567	9.514	4.935	.01745	.87000	7.410	
TURB EXIT	18.868	1250.58	433.46	2.430	3.437	1.284	3.297	.01745			
PLUS COOLING	18.863	1247.10	432.41	2.455	3.468	1.284	3.291	.01727			.22113
EXHT/STATIC COND	14.696	1247.10	432.41	2.455	4.453	1.000	3.291	.01727			

ALTITUDE (FT) = 0.  
 SPEED OF SOUND = 1190.44  
 DELTA TEMP FROM 1962 ATMOS = 71.00  
 DELTA PRESS FROM 1962 PRESS = 0.00  
 NO OF COMP STAGES = 2  
 NO OF TURB STAGES = 1  
 DESIGN SHAFT HP = 165.0000  
 SHP EXTRACTED = 177.86735  
 SHP EXTRACTED, COR FOR SL = 189.651  
 SHP EXTRACTED, COR FOR MECH EFF = 165.00000  
 HP EXTRACTED FOR ACCESSORIES = 9.500  
 HP NEEDED FOR LPC = 115.943  
 HP NEEDED FOR MPC = 548.26281  
 CALCULATED FUEL FLOW = 150.0000  
 FUEL FLOW COEF = 7.09711  
 MAIN CORB FUEL HEATING VALUE AT T4 FOR JP4 = 18400.0  
 WORK OF LPC (BTU/LB) = 32.973  
 LPC SEAL LEAKAGE FLOW FRACTION = 0.00000  
 WORK OF MPC (BTU/LB) = 155.919  
 MPC SEAL LEAKAGE FLOW FRACTION = .02000  
 MPT WORK PERCENT = 0.000  
 HORSEPOWER OF MPT = 144.22645  
 LPT WORK PERCENT = 1.000  
 HORSEPOWER OF LPT = 842.07305  
 NET THRUST = 86.86823  
 GROSS THRUST = 86.86823  
 NET THRUST/ENGINE AIRFLOW = 34.95217  
 THERMAL EFF = .16396  
 EXHAUST EXIT VELOCITY = 1138.582  
 ENGINE UNINSTALLED SFC (LB FUEL/HR-HP) = .4091

\*\*\*INPUT VALUES\*\*\*

ALTITUDE (FT) = 0.  
PRESSURE (PSI) = 14.696  
DELTA TEMP FROM 1962 ATMOS = 71.00000

BEGIN INDICATOR = 0  
END INDICATOR = 0

NO OF COMPRESSOR STAGES = 2  
NO OF TURBINE STAGES = 1

FLOW = 2.48535  
MECH EFF = .98000  
HPACC EXTRACTED FOR ACCESS = 9.50  
DESIGN SHAFT POWER = 165.0000

INLET DUCT PRESS LOSS = .04  
LPC PRESS RATIO = 1.794  
LPC EFF = .78000  
LPC SEAL LEAKAGE = 0.0  
LPC BLEED, TO BE USED LATER

INTER-COMP PRESS LOSS = .01  
BLEED DUCT PRESS LOSS = .014

HPC PRESS RATIO = 6.000  
HPC EFF = .74600  
HPC SEAL LEAKAGE = .02

MAIN COMB PRESS LOSS = .07000  
MAIN COMBUSTION EFF = .99500  
DESIGN FUEL FLOW (LB/HR) = 190.00  
MAIN COMB FUEL HEATING VALUE AT T4 FOR JP4 = 0.  
COMB DISCHARGE TEMP (DEGREE RANKINE) = 2559.67  
HPT INLET NOZ COOLING/HPC INLET FLOW = 0.00000

HPT PRESS RATIO = 1.000  
HPT EFF = .80  
TURB COOLING/HPC INLET FLOW = 0.00000

INTER TURB PRESS LOSS (P5-P51)/P5 = 0.00

LPT PRESS RATIO = 9.418  
LPT EFF = .87000  
EXHAUST DUCT PRESS LOSS (P53-P11)/P53 = 0.0  
LPT COOLING/HPC INLET FLOW = .01000

Example B - 2 Stage Compressor, 1 Stage Turbine  
With Fuel Heating Value Calculated

STATION	PRESSURE-PSI	TEMP-DEG.F	ENTHALPY	FLOW	COR FLOW	DELTA	THETA	FUEL/AIR	EFF	PRESS RATIO	DEL P
AMBIENT	14.696	130.00	140.93			1.000	1.137				
LP COMP INLET	14.108	130.00	140.93	2.485	2.760	.960	1.137		.78000	1.794	.04000
LP COMP EXIT	25.310	266.94	173.90	2.485	1.708	1.722	1.401				.01000
HP COMP INLET	25.057	266.94	173.90	2.485	1.725	1.705	1.401		.74600	6.000	
HPACOMP EXIT/											
BURNER INLET	150.342	890.51	329.82	2.388	.377	10.230	2.603			10.656	
BURNER EXIT	139.818	2201.21	712.87	2.441	.581	9.514	5.130	.02210	.99500		.07000
TURB INLET	139.818	2201.23	712.87	2.441	.581	9.514	5.130	.02210	.87000	9.418	
TURB EXIT	14.846	1244.78	433.99	2.441	4.380	1.010	3.286	.02210			
PLUS COOLING	14.846	1241.40	432.94	2.466	4.421	1.010	3.280	.02187			
EXHT/STATIC COND	14.696	1241.40	432.94	2.466	4.466	1.000	3.280	.02187			.01009

\*\*\*OUTPUT VALUES\*\*\*

ALTITUDE (FT) = 0.  
 SPEED OF SOUND = 1190.44  
 DELTA TEMP FROM 1962 ATMOS = 71.00  
 DELTA PRESS FROM 1962 PRESS = 0.00

NO OF COMP STAGES = 2  
 NO OF TURB STAGES = 1

DESIGN SHAFT HP = 165.0000  
 SHP EXTRACTED = 298.94979  
 SHP EXTRACTED, COR FOR SL = 318.755  
 SHP EXTRACTED, COR FOR MECH EFF = 283.66079  
 HP EXTRACTED FOR ACCESSORIES = 9.500  
 HP NEEDED FOR LPC = 115.943  
 HP NEEDED FOR MPC = 548.26281

CALCULATED FUEL FLOW = 190.0000  
 FUEL FLOW COEF = 8.81705  
 MAIN COMB FUEL HEATING VALUE AT T4 FOR JP4 = 16829.5

WORK OF LPC (BTU/LB) = 32.973  
 LPC SEAL LEAKAGE FLOW FRACTION = 0.00000

WORK OF MPC (BTU/LB) = 155.919  
 MPC SEAL LEAKAGE FLOW FRACTION = .02000

HPT WORK PERCENT = 0.000  
 HORSEPOWER OF HPT = 144.22645

LPT WORK PERCENT = 1.000  
 HORSEPOWER OF LPT = 963.15549

NET THRUST = 17.79274  
 GROSS THRUST = 17.79274  
 NET THRUST/ENGINE AIRFLOW = 7.15906  
 THERMAL EFF = .23786  
 EXHAUST EXIT VELOCITY = 232.159  
 ENGINE UNINSTALLED SFC (LB FUEL/HR-HP) = .6698

STATION	PRESSURE-PSI	TEMP-DEG.F	ENTHALPY	FLOW	COR FLOW	DELTA	THETA	FUEL/AIR	EFF	PRESS RATIO	DEL P
AMBIENT	14.096	130.00	140.93			1.000	1.137				
LP COMP INLET	14.108	130.00	140.93	2.485	2.760	1.000	1.137		.78000	1.794	.04000
LP COMP EXIT	25.310	266.94	173.90	2.485	1.708	1.722	1.401				.01000
HP COMP INLET	25.057	266.94	173.90	2.485	1.725	1.705	1.401		.74600	6.000	
HPACOMP EXIT											
BURNER INLET	150.342	890.51	329.82	2.388	.377	10.230	2.603			10.656	
BURNER EXIT	139.818	2201.21	712.87	2.441	.581	9.514	5.130	.02210	.99500		.07000
TURB INLET	139.818	2201.23	712.87	2.441	.581	9.514	5.130	.02210	.87000	6.614	
TURB EXIT	21.139	1369.28	469.05	2.441	3.187	1.438	3.526	.02210			
PLUS COOLING	21.139	1364.74	467.64	2.466	3.215	1.438	3.517	.02187			
EXHT/STATIC COND	14.696	1364.74	467.65	2.466	4.625	1.000	3.517	.02187			.30479

ALTITUDE (FT) = 0.

SPEED OF SOUND = 1190.44

DELTA TEMP FROM 1962 ATMOS = 71.00

DELTA PRESS FROM 1962 PRESS = 0.00

NO OF COMP STAGES = 2

NO OF TURB STAGES = 1

DESIGN SHAFT HP = 165.0000

SHP EXTRACTED = 177.86735

SHP EXTRACTED, COR FOR SL = 189.651

SHP EXTRACTED, COR FOR MECH EFF = 165.00000

HP EXTRACTED FOR ACCESSORIES = 9.500

HP NEEDED FOR LPC = 115.943

HP NEEDED FOR MPC = 548.26281

CALCULATED FUEL FLOW = 190.0000

FUEL FLOW COEF = 8.81705

MAIN COMB FUEL HEATING VALUE AT 14 FOR JP4 = 16829.5

WORK OF LPC (BTU/LB) = 32.973

LPC SEAL LEAKAGE FLOW FRACTION = 0.00000

WORK OF MPC (BTU/LB) = 155.919

MPC SEAL LEAKAGE FLOW FRACTION = .02000

MPT WORK PERCENT = 0.000

HORSEPOWER OF MPT = 144.22645

LPT WORK PERCENT = 1.000

HORSEPOWER OF LPT = 842.07305

NET THRUST = 107.69671

GROSS THRUST = 107.69671

NET THRUST/ENGINE AIRFLOW = 43.33268

THERMAL EFF = .14152

EXHAUST EXIT VELOCITY =

1405.220

ENGINE UNINSTALLED SFC (LB FUEL/HR-HP) = 1.1515

THIS PROGRAM WAS DEVELOPED BY COMPONENTS BRANCH TURBINE ENGINE DIVISION  
MODIFIED BY POWER DIVISION U.S. AIR FORCE AERO PROPULSION LABORATORY

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## EXPENDABLE GASIFIER JFS

## \*\*\*INPUT VALUES\*\*\*

ALTITUDE (FT) = 0.  
PRESSURE (PSI) = 14.696  
DELTA TEMP FROM 1962 ATMOS = 0.00000

BEGIN INDICATOR = 1  
END INDICATOR = 0

NO OF COMPRESSOR STAGES = 1  
NO OF TURBINE STAGES = 4

FLOW = 3.86200  
MECH EFF = .98000  
HPACC EXTRACTED FOR ACCESS = 4.00  
DESIGN SHAFT POWER = 230.0000

INLET DUCT PRESS LOSS = .01  
LPC PRESS RATIO = 1.000  
LPC EFF = 1.00000  
LPC SEAL LEAKAGE = 0.0  
LPC BLEED, TO BE USED LATER

INTER-COMP PRESS LOSS = 0.00  
BLEED DUCT PRESS LOSS = 0.000

HPC PRESS RATIO = 2.827  
HPC EFF = .79200  
HPC SEAL LEAKAGE = 0.00

MAIN COMB PRESS LOSS = .12300  
MAIN COMBUSTION EFF = .95000  
DESIGN FUEL FLOW (LB/HR) = 0.00  
MAIN COMB FUEL HEATING VALUE AT T4 FOR JP4 = 18400.  
COMB DISCHARGE TEMP (DEGREE RANKINE) = 2260.00  
HPT INLET NOZ COOLING/HPC INLET FLOW = 0.00000

HPT PRESS RATIO = 1.540  
HPT EFF = .83  
TURB COOLING/HPC INLET FLOW = 0.00000

INTER TURB PRESS LOSS  $(P5-P51)/P5 = .02$

LPT PRESS RATIO = 1.600  
LPT EFF = .85000  
EXHAUST DUCT PRESS LOSS  $(P53-P1)/P53 = 0.0$   
LPT COOLING/HPC INLET FLOW = 0.00000

Example C - 1 Stage Compressor, 1 Stage Turbine with Power Turbine

\*\*\*OUTPUT VALUES\*\*\*

LPC NOT USED  
PRESSURE RATIO CALCULATED AS NEEDED FOR HPT  
ERROR NUMBER 39 DETECTED BY SORT

STATION	PRESSURE-PSI	TEMP-DEG.F	ENTHALPY	FLOW	COR FLOW	DELTA	THETA	FUEL/AIR	EFF	PRESS RATIO	DEL P
AMBIENT	14.696	59.00	123.92			1.000	1.000				
HP COMP INLET	14.549	59.00	123.92	3.862	3.901	.990	1.000		.79200	2.827	
HP COMP EXIT											
BURNER INLET	41.130	295.00	178.27	3.816	1.634	2.799	1.436				
BURNER EXIT	36.071	1900.33	595.32	3.916	3.330	2.454	4.357	.02625	.95000	2.827	.12300
TURB 1 INLET	36.071	1600.33	596.56	3.916	3.330	2.454	4.357	.02625	.82500	1.564	
TURB 1 EXIT	23.069	1615.46	542.23	3.916	3.330	1.570	4.001	.02625			.02000
TURB 1 EXIT											
PLUS COOLING	22.608	1615.46	542.23	1.014	5.091	1.538	4.001	.02625			
TURB 2 INLET	22.608	1615.46	542.23	3.916	5.091	1.538	4.001	.02625	.85000	1.600	
TURB 2 EXIT	14.130	1429.37	488.37	3.916	7.772	.961	3.642	.02625			
TURB 2 EXIT											
PLUS COOLING	14.130	1429.37	488.37	3.916	7.772	.961	3.642	.02625			
EXHT/STATIC COND	14.090	1429.37	488.36	3.916	7.473	1.000	3.642	.02625			-.04007

ALTITUDE (FT) = 0.  
SPEED OF SOUND = 1116.99  
DELTA TEMP FROM 1962 AT40S = 0.00  
DELTA PRESS FROM 1962 PRESS = 0.00

NO OF COMP STAGES = 1  
NO OF TURB STAGES = 4

DESIGN SHAFT HP = 230.0000  
SHP EXTRACTED = 298.39499  
SHP EXTRACTED, COR FOR SL = 298.395  
SHP EXTRACTED, COR FOR MECH EFF = 292.42709  
HP EXTRACTED FOR ACCESSORIES = 4.000  
HP NEEDED FOR LPC = 0.000  
HP NEEDED FOR HPC = 296.99891

CALCULATED FUEL FLOW = 360.5688  
FUEL FLOW COEF = 70.37508  
PAIN COMB FUEL HEATING VALUE AT T4 FOR JP4 = 18400.0

WORK OF LPC (BTU/LB) = 0.000  
LPC SEAL LEAKAGE FLOW FRACTION = 0.00000  
WORK OF HPC (BTU/LB) = 54.355  
HPC SEAL LEAKAGE FLOW FRACTION = 0.00000

HPT WORK PERCENT = .502  
HORSEPOWER OF HPT = 291.25684

LPT WORK PERCENT = .498  
HORSEPOWER OF LPT = 298.39499  
THIS IS ACTUALLY A POWER TURBINE

NET THRUST = 1  
GROSS THRUST = 1  
NET THRUST/ENGINE AIRFLOW = 29 1  
THERMAL EFF = .11443  
EXHAUST EXIT VELOCITY = 1  
ENGINE UNINSTALLED SFC (LB FUEL/HR-HP) = 1.2330

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STATION	PRESSURE-PSI	TEMP-DEG.F	ENTHALPY	FLOW	COR FLOW	DELTA	THETA	FUEL/AIR	EFF	PRESS RATIO	DEL P
AMBIENT	14.696	59.00	123.92			1.000	1.000				
HP COMP INLET	14.696	59.00	123.92	3.862	3.901	.996	1.000		.79200	2.827	
HP COMP EXIT/	14.549	59.00	123.92								
BURNER INLET	41.130	285.00	178.27	3.816	1.634	2.799	1.436			2.827	
BURNER EXIT	36.071	1800.33	595.32	3.916	3.330	2.454	4.357	.02625	.95000		.12300
TURB 1 INLET	36.071	1800.33	595.32	3.916	3.330	2.454	4.357	.02625	.82500	1.564	
TURB 1 EXIT	23.069	1615.46	542.23	3.916	3.330	1.570	4.001	.02625			.02000
TURB 1 EXIT	22.608	1615.46	542.23	1.014	5.091	1.538	4.001	.02625			
TURB 2 INLET	22.608	1615.46	542.23	3.916	5.091	1.538	4.001	.02625	.85000	1.441	
TURB 2 EXIT	15.691	1469.36	499.86	3.916	7.073	1.068	3.719	.02625			
TURB 2 EXIT	15.691	1469.36	499.86	3.916	7.073	1.068	3.719	.02625			
PLUS COOLING	15.691	1469.36	499.86	3.916	7.073	1.068	3.719	.02625			.06340
EXHT/STATIC COND	14.696	1469.36	499.86	3.916	7.552	1.000	3.719	.02625			

ALTITUDE (FT) = 0.  
 SPEED OF SOUND = 1116.99  
 DELTA TEMP FROM 1962 AT405 = 0.00  
 DELTA PRESS FROM 1962 PRESS = 0.00

NO OF COMP STAGES = 1  
 NO OF TURB STAGES = 4

DESIGN SHAFT HP = 230.0000  
 SHP EXTRACTED = 234.69388  
 SHP EXTRACTED, COR FOR SL = 234.694  
 SHP EXTRACTED, COR FOR MECH EFF = 230.00000  
 HP EXTRACTED FOR ACCESSORIES = 4.000  
 HP NEEDED FOR LPC = 0.000  
 HP NEEDED FOR MPC = 296.99891

CALCULATED FUEL FLOW = 360.5688  
 FUEL FLOW COEF = 70.37508  
 MAIN COMB FUEL HEATING VALUE AT 14 FOR JP4 = 18400.0

WORK OF LPC (BTU/LB) = 0.000  
 LPC SEAL LEAKAGE FLOW FRACTION = 0.00000

WORK OF MPC (BTU/LB) = 54.355  
 MPC SEAL LEAKAGE FLOW FRACTION = 0.00000

LPT WORK PERCENT = .562  
 HORSEPOWER OF HPT = 300.99891

LPT WORK PERCENT = .438  
 HORSEPOWER OF LPT = 214.69388  
 THIS IS ACTUALLY A POWER TURBINE

NET THRUST = 75.77207  
 GROSS THRUST = 75.77207  
 NET THRUST/ENGINE AIRFLOW = 19.61990  
 THERMAL EFF = .04000  
 EXHAUST EXIT VELOCITY = 622.577  
 ENGINE UNINSTALLED SEC (LB FUEL/HR-HP) = 1.5677

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APPENDIX B  
FLOWCHART AND LISTING

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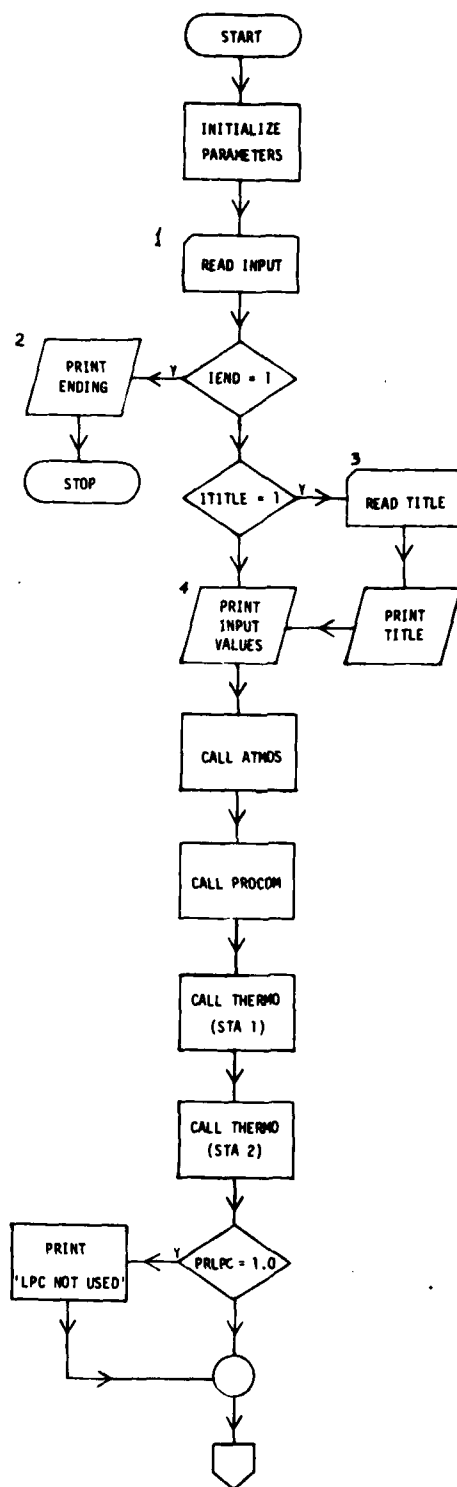


Figure 3 - Flowchart of APU

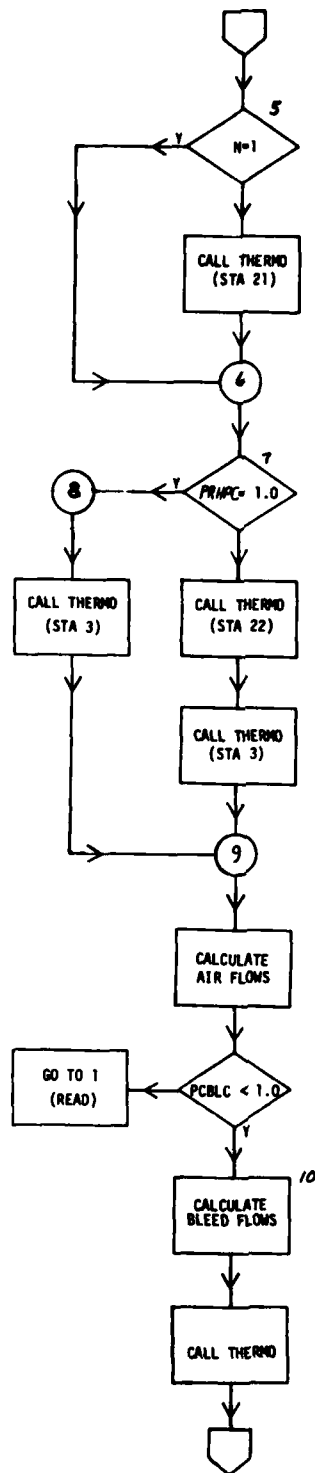


Figure 4 - Flowchart of APU

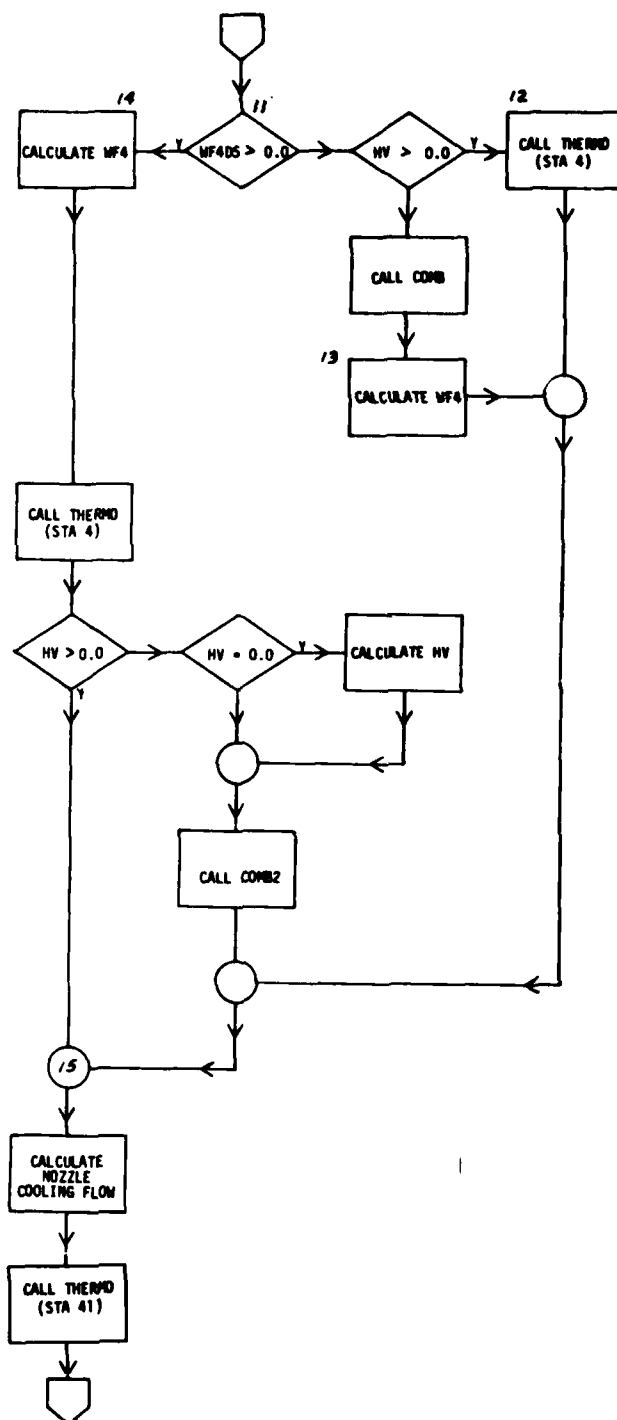


Figure 5 - Flowchart of APU

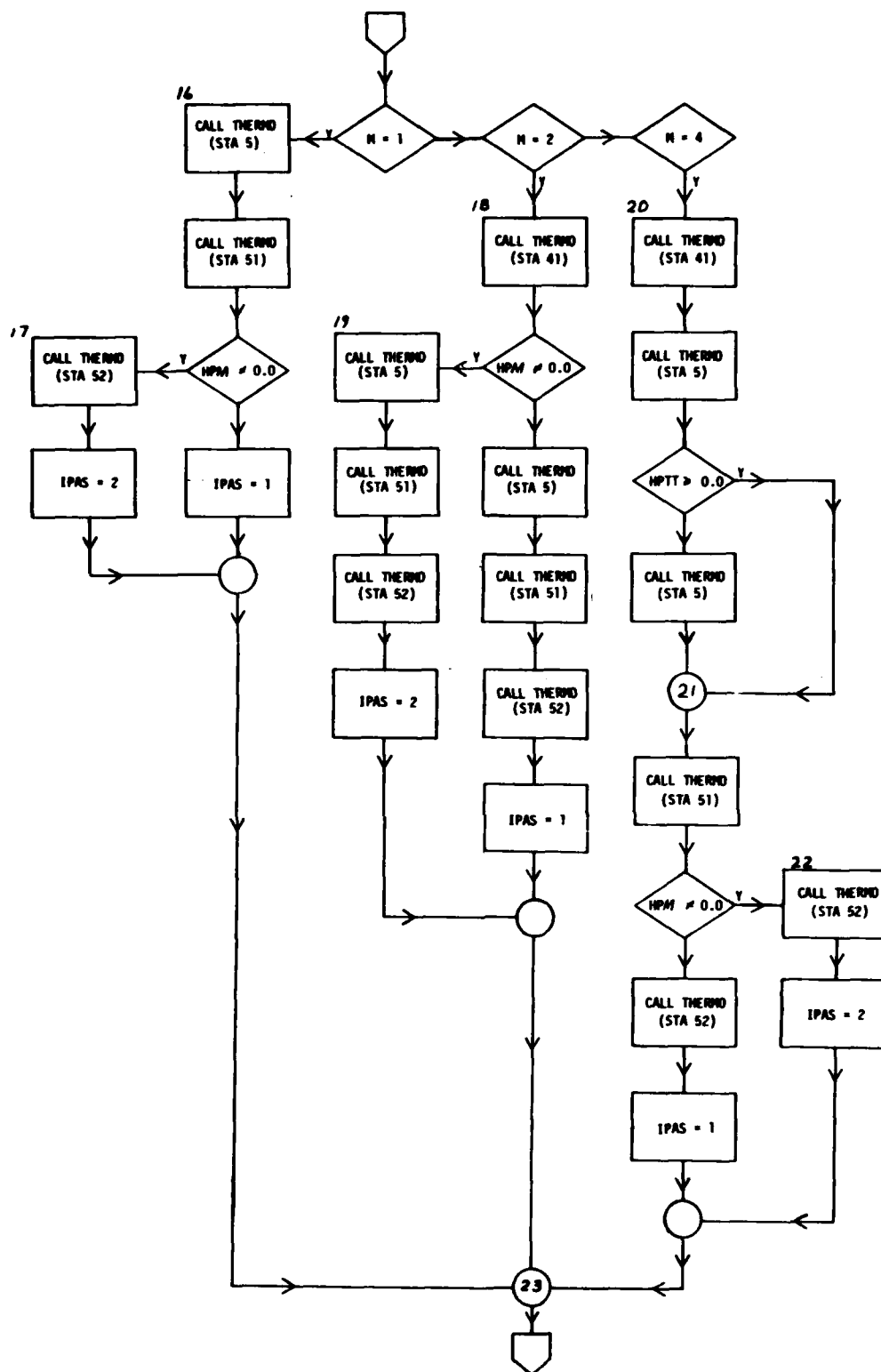


Figure 6 - Flowchart of APU

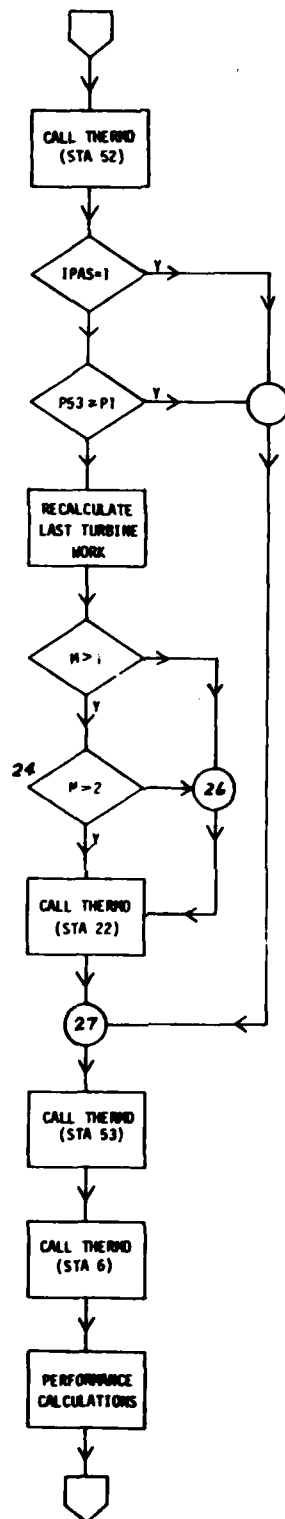


Figure 7 - Flowchart of APU

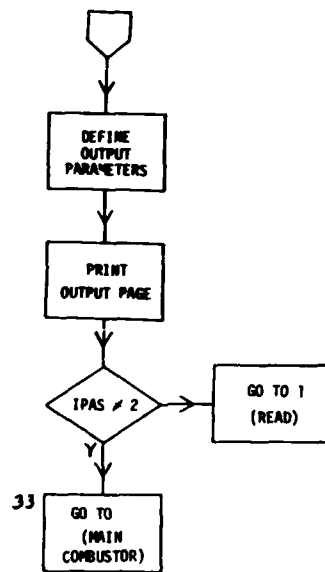


Figure 8 - Flowchart of APU

```

PROGRAM APU (INPUT, OUTPJT, TAPE5=INPUT,
$ TAPE6=OUTPUT)
COMMON /PARAM/ ETALPC, ETAHPC, ETAB, ETAHPT,
$ ETALPT, PRLPC,
1 PRHPC, DPB, DPT, DPE, DPIN, DPC, HPACC, HPDS,
$ LCSL, HCSSL,
2 PCBLC, T4, ETAM
DIMENSION ANUM (2), AWORD (2), BWORD (2), TITLE
$ (11)
REAL LCSL
DATA AWORD / 3HATM, 3HPSI /
DATA ANUM / 3H , 3H 2 /
DATA BWORD / 3HLP , 6HHPACC /

C
NAMELIST / INPUT / ALTP, DELPAMB, DELTAMB, PRES,
$ WAENG, PRHPT,
1 DPBLEED, DPIN, DPC, PRLPC, PRHPC, LCSL, HCSSL,
$ ETALPC, ETAHPC,
2 ETAHPT, ETALPT, T4, DPT, M, HV, N, ETAB, WF4DS,
$ DPB, PCBLT4,
3 PCBLHP, ETAM, PCBLLP, ITITLE, PRLPT, HPDS, HPACC,
$ IEND

C
C STATION 1 - AMBIENT CONDITIONS
C STATION 2 - LP COMPRESSOR INLET
C STATION 21 - LP COMPRESSOR DISCHARGE
C STATION 22 - HP COMPRESSOR INLET
C STATION 3 - HP COMPRESSOR DISCHARGE/BURNER INLET
C STATION 4 - MAIN COMBUSTOR DISCHARGE
C STATION 41 - HP TURBINE INLET
C STATION 5 - HP TURBINE DISCHARGE BEFORE COOLING FLOW
C $ HAS BEEN ADDED
C STATION 51 - LP TURBINE INLET
C STATION 52 - LP TURBINE DISCHARGE BEFORE COOLING FLOW
C $ HAS BEEN ADDED
C STATION 53 - LP TURBINE DISCHARGE INCLUDING COOLING
C $ FLOW EFFECTS
C STATION 6 - EXHAUST DUCT EXIT
C ALTP - ALTITUDE IN FEET
C DPBLEED - BLEED DUCT PRESSURE LOSS
C BLTOTL - HP COMPRESSOR TOTAL BLEED (FRACTION OF WA22)
C BLT4 - HP TURBINE INLET NOZZLE COOLING FLOW (FRACT OF
C $ BLTOTL)
C BLHPT - HP TURBINE DISCHARGE COOLING FLOW (FRACT OF
C $ BLTOTL)
C BLLPT - LP TURBINE DISCHARGE COOLING FLOW (FRACT OF
C $ BLTOTL)
C CS - AMBIENT SPEED OF SOUND (FPS)
C DELTAMB - CHANGE IN AMBIENT TEMPERATURE FROM 1962
C $ ATMOSPHERE

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C DELPAMB - CHANGE IN AMBIENT PRESSURE FROM 1962 PRESSURE  
 C GPB - MAIN COMBUSTOR PRESSURE LOSS  $(P3-P4)/P3$   
 C JPC - INTER-COMPRESSOR PRESSURE LOSS  $(P22L-P22)/P22L$   
 C DPIN - INLET DUCT PRESSURE LOSS  
 C DPE - EXHAUST DUCT PRESSURE LOSS  $(P53-P1)/P53$   
 C DPT - INTER-TURBINE PRESSURE LOSS  $(P5-P51)/P5$   
 C FAR - FUEL FLOW/AIRFLOW  
 C ETALPC - LP COMPRESSOR EFFICIENCY  
 C ETAHPC - HP COMPRESSOR EFFICIENCY  
 C ETAB - MAIN COMBUSTION EFFICIENCY  
 C ETAHPT - HP TURBINE EFFICIENCY  
 C ETALPT - LP TURBINE EFFICIENCY  
 C ETAM - MECHANICAL EFFICIENCY  
 C ETATHM - THERMAL EFFICIENCY  
 C FN/WA - NET THRUST/TOTAL ENGINE AIRFLOW  
 C FG - GROSS THRUST  
 C FN - NET THRUST  
 C HS6 - STATIC ENTHALPY AT EXHAUST EXIT (BTU/LB MASS)  
 C HV - MAIN COMBUSTOR FUEL HEATING VALUE AT T4 FOR JP-  
 C \$ 4  
 C HPLPC - HORSEPOWER NEEDED FOR LP COMPRESSOR  
 C HPHPC - HORSEPOWER NEEDED FOR HP COMPRESSOR  
 C HPACC - HORSEPOWER EXTRACTED FOR ACCESSORIES  
 C HPM - SHP EXTRACTED, CORRECTED FOR MECHANICAL  
 C \$ EFFICIENCY  
 C HPMAMB - SHP EXTRACTED, CORRECTED FOR S.L., STANDARD DAY  
 C \$ CONDITIONS  
 C HPEXT - SHAFT HORSEPOWER EXTRACTED  
 C HPDS - DESIGN SHAFT POWER  
 C HCSL - HPC SEAL LEAKAGE/HPC FLOW  
 C LCSL - LPC SEAL LEAKAGE/LPC FLOW  
 C M - NUMBER OF TURBINE STAGES  
 C = 1, ONE TURBINE APU  
 C = 2, TWO TURBINE APU  
 C = 4, TWO TURBINE APU, ONE OF WHICH IS A POWER  
 C \$ TURBINE  
 C N - NUMBER OF COMPRESSOR STAGES  
 C PCT - DESIGN POINT WORK LOAD PERCENTAGE PER TURBINE  
 C PRES - A MULTIPLIER ON PRESSURE VALUES FOR OUTPUT  
 C PROA - OVERALL CORE COMPRESSION RATIO  $(P3/P2)$   
 C PRHPT - HP TURBINE PRESSURE RATIO  
 C PRLPT - LP TURBINE PRESSURE RATIO  
 C PC9LA - ACCESSORY AIR BLEED FLOW EXTRACTED FROM HP  
 C \$ COMPRESSOR/  
 C HPC INLET FLOW  
 C PCBLT4 - HP TURBINE INLET NOZZLE COOLING FLOW / HP  
 C \$ COMPRESSOR  
 C INLET FLOW  
 C PCBLHP - HP TURBINE EXIT COOLING FLOW / HP COMPRESSOR  
 C \$ INLET FLOW

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C PCBLLP - LP TURBINE EXIT COOLING FLOW / HP COMPRESSOR
C $      INLET FLOW
C PRLPC  - LP COMPRESSOR PRESSURE RATIO
C PRHPC  - HP COMPRESSOR PRESSURE RATIO
C SFCU   - UNINSTALLED SPECIFIC FUEL CONSUMPTION (LB FUEL/
C $      HR-HP)
C T4     - COMBUSTOR DISCHARGE TEMPERATURE (DEGREE
C $      RANKINE)
C TS6    - STATIC TEMPERATURE AT EXHAUST EXIT (DEGREE F)
C THG6   - CORE GROSS THRUST PER POUND TOTAL AIRFLOW
C V6     - EXHAUST EXIT VELOCITY
C WA22   - AIRFLOW AT HPC INLET/WAENG
C WAENG  - TOTAL ENGINE INLET AIRFLOW
C WF     - FUEL FLOW RATE (LB/SEC)
C WF4DS  - DESIGN FUEL FLOW (LB/HR)
C WG     - MASS FLOW RATE (INCLUDES FUEL FLOW) (LB/SEC)
C WLPC   - WORK OF THE LP COMPRESSOR (BTU/LB)
C WHPC   - WORK OF THE HP COMPRESSOR (BTU/LB)
C
C *** CONSTANTS
C DATA  G, AJ, IEND, IP / 32.174349, 778.26, 0, 1 /
C PRES   = WAENG = PRLPC = PRHPC = ETALPC = ETAHPC
C $ = 1.
C ETAHPT = ETALPT = ETAM = ETAB = PRHPT = PRLPT =
C $ 1.
C WF4DS  = DELTAMB = DELPAMB = DPIN = DPB = 0.
C DPC    = DPT = DPE = LOSL = HOSL = PCBLC = PCBLT4
C $ = 0.
C PCBLLP = PCBLLP = HPACC = HPDS = DPBLEED = HV =
C $ 0.
C IPAS   = 0
C IN     = IB = 2
1 READ (5, INPUT)
  IF (IEND .EQ. 1) WRITE (6, 100)
  IF (IEND .EQ. 1) STOP
  IF (ITITLE - 1) 2, 3, 3
2 WRITE (6, 101)
  GO TO 4
3 READ (5, 102) (TITLE(I), I=1, 11)
  WRITE (6, 103) (TITLE(I), I=1, 11)
  WRITE (6, 104)
4 WRITE (6, 105) ALT
  WRITE (6, 106) PRES
  WRITE (6, 107) DELTAMB
  WRITE (6, 108) ITITLE
  WRITE (6, 109) IEND
  WRITE (6, 110) N
  WRITE (6, 111) M
  WRITE (6, 112) WAENG

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WRITE (6, 113) ETAM
WRITE (6, 114) HPACC
WRITE (6, 115) HPDS
WRITE (6, 116) DPIN
WRITE (6, 117) PRLPC
WRITE (6, 118) ETALPC
WRITE (6, 119) LCSL
WRITE (6, 120)
WRITE (6, 121) DPC
WRITE (6, 122) DPBLFED
WRITE (6, 123) PRHPC
WRITE (6, 124) ETAHPC
WRITE (6, 125) HCSL
WRITE (6, 126) DPB
WRITE (6, 127) ETA3
WRITE (6, 128) WF4DS
WRITE (6, 129) HV
WRITE (6, 130) T4
WRITE (6, 131) PCBLT4
WRITE (6, 132) PRHPT
WRITE (6, 133) ETAHPT
WRITE (6, 134) PCBHP
WRITE (6, 135) DPT
WRITE (6, 136) PRLPT
WRITE (6, 137) ETALPT
WRITE (6, 138) DPC
WRITE (6, 139) PCBLLP
WRITE (6, 140)
CALL ATMOS (ALTP, T11, P1)
T1      = T11 + DELTAMB
P1      = P1 + DELPAMB
CALL PROCOM (0.0, T1, CS, X1, X2, X3, X4, X5)

```

```

C
C *** BEGINNING OF INLET
CALL THERMO (P1, H1, T1, S1, AMW1, CP1, GA1, 0, 0.0,
$ 0)
H2      = H1
P2      = P1 * (1.0 - DPIN)
CALL THERMO (P2, H2, T2, S2, AMW2, CP2, GA2, 0, 0.0,
$ 1)
HPM     = 0.0
IF (PRLPC .EQ. 1.0) GO TO 34
IF (PRLPC .LT. 1.0 .OR. ETALPC .GT. 1.0) GO TO 35
IF (PRHPC .LT. 1.0 .OR. ETAHPC .GT. 1.0) GO TO 35
5 IF (N .EQ. 1) GO TO 5

```

```

C
C *** BEGINNING OF LP COMPRESSOR
P21     = PRLPC * P2
RATIOA  = (GA2 - 1.) / GA2
WLPC    = (CP2 * T2 * (((P21 / P2) ** RATIOA) -
$ 1.)) / ETALPC

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      H21      = WLPC + H2
      CALL THERMO (P21, H21, T21, S21, AMW21, CP21, GA21,
$ 0, 0.0, 1)
      GO TO 7
6  P21      = P2
   T21      = T2
   H21      = H2
   WLPC     = 0.0
7  IF (PRHPC .EQ. 1.0) GO TO 8
C
C *** BEGINNING OF HP COMPRESSOR
   P22      = P21 * (1.0 - DPC)
   H22      = H21
   T22      = T21
   CALL THERMO (P22, H22, T22, S22, AMW22, CP22, GA22,
$ 0, 0.0, 0)
   P3       = PRHPC * P22
   RATIO8    = (GA22 - 1.) / GA22
   WHPC     = (CP22 * T22 * (((P3 / P22) ** RATIO8) -
$ 1.)) / ETAHPC
   H3       = WHPC + H22
   CALL THERMO (P3, H3, T3, S3, AMW3, CP3, GA3, 0, 0.0,
$ 1)
   RATIO3    = (GA3 - 1.0) / GA3
   GO TO 9
8  P22      = P21
   P3       = P22
   T3       = T21
   H3       = H21
   WHPC     = 0.0
   CALL THERMO (P3, H3, T3, S3, AMW3, CP3, GA3, 0, 0.0,
$ 0)
9  PROA     = PRHPC * PRLPC * (1.0 - DPC)
C
C *** AIR FLOWS, FRACTIONS OF WAENG.
   WA2      = 1.0
   WA21     = WA2 * (1.0 - LCS.)
   WA22     = WA21
   WAIRHP   = CP3 * T3 * (((P3 / P1) ** RATIO3) - 1.0)
   BLA      = (HPALC * .7068) / WAIRHP
   PCBLA    = BLA / (WA22 * WAENG)
   PCBLG    = PCBLT4 + PCBL4P + PCBLLP + PCBLA
   WA3      = WA22 * (1.0 - HCS. - PCBLG)
C
   IF ((PCBLG .LT. 1.0)) GO TO 10
   PRINT *, "PERCENTS OF BLEED FLOWS .GT. 1.0--HALT
$ EXECUTION"
   GO TO 1
10  BLT4     = PCBLT4 * WA22

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BLHPT      = PCBLHP * WA22
BLLP       = PCBLLP * WA22
BLP        = P3 * (1.0 - DDBLEED)
HPLPC      = (WLPC * WA2 * WAENG) / .7068
HPHPC      = (WHPC * WA22 * WAENG) / .7068
TB         = T3
CALL THERMO (BLP, HB, TB, SB, AMWB, CPB, GAB, 0,
$ 0.0, 0)

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C

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C *** BEGINNING OF MAIN COMBUSTOR
IF (WF4DS .LT. 0.0 .OR. T4 .LT. 3.0 .OR.
$ ETAB.GT.1.0) GO TO 35
11 IF (WF4DS .GT. 0.0) GO TO 14
IF (HV .GT. 0.0) GO TO 12
CALL COMB (P3, T4, H3, ETAB, DP3, P4, H4, S4, FAR4,
$ HV)
GO TO 13
12 P4      = P3 * (1.0 - DDB)
FAR4      = (.276 * (T4 - T3)) / ((ETAB * HV) -
$ (.276 * (T4 -
1 T3)))
CALL THERMO (P4, H4, T4, S4, AMW4, CP4, GA4, 1,
$ FAR4, 0)
FAR4      = (CP4 * (T4 - T3)) / ((ETAB * HV) - (CP4
$ * (T4 - T3)))
13 WF4     = FAR4 * WA3
GO TO 15
14 WF4     = WF4DS / (WAENG * 3600.)
FAR4      = WF4 / WA3
P4        = P3 * (1.0 - DDB)
CALL THERMO (P4, H4, T4, S4, AMW4, CP4, GA4, 1,
$ FAR4, 0)
IF (HV .GT. 0.) GO TO 15
IF (HV .EQ. 0.0) HV = ( (CP4 * (T4 - T3) / FAR4) +
$ CP4 * (T4 -
1 T3)) / ETAB
CALL COMB2 (P3, T4, H3, ETAB, DP3, P4, H4, S4, FAR4,
$ HV)
15 WG4     = WA3 + WF4
P41       = P4
WG41      = WG4 + BLT4
FAR41     = WF4 / (WA3 + BLT4)
H41       = (H4 * WG4 + HB * BLT4) / WG41
CALL THERMO (P41, H41, T41, S41, AMW41, CP41, GA41,
$ 1, FAR41, 1)
IF (BLT4 .LE. 0.0) T41 = T4
IF (PRHPT .LT. 1.0 .OR. ETAPPT .GT. 1.0) GO TO 37
IF (PHLPT .LT. 1.0 .OR. ETALPT .GT. 1.0) GO TO 37
IF (M .EQ. 1) GO TO 16
IF (M .EQ. 2) GO TO 18

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      IF (M.EQ. 4) GO TO 29
0
0 *** ONE TURBINE APU
16 P5 = P41
   PRHPT = P41 / P5
   H5 = H41
   T5 = T41
   FAR5 = FAR41
   CALL THERMO (P5, H5, T5, S5, AMW5, CP5, GA5, 1,
$ FAR5, 1)
   P51 = P5
   H51 = H5
   T51 = T5
   WG51 = WG41
   FAR51 = FAR41
   CALL THERMO (P51, H51, T51, S51, AMW51, CP51, GA51,
$ 1, FAR51, 1)
   IF (HPM.NE. 0.0) GO TO 17
   RATIO = (GA51 - 1.0) / GA51
   TWORK = ETALPT * CP51 * T51 * (1.0 - ((1.0 /
$ PRLPT) **
1 RATIO))
   DHTL = TWORK
   H52 = H51 - DHTL
   P52 = P51 / PRLPT
   HPLT = (TWORK * WG51 * WAENG) / .7068
   HPEXT = HPLT - HPLPC - HPHPC
   HPM = (HPEXT - HPACC) * ETAM
   PCT1 = 0.0
   PCT2 = 1.0
   IPAS = 1
   GO TO 23
17 HPBTU = ((HPACC + (HPJS / ETAM)) * .7068) /
$ (WG51 * WAENG)
   DHTL = HPBTU + (((H3 - 422) * WA22 + (H21 - H2)
$ * WA2) /
1 WG51)
   H52 = H51 - DHTL
   P52 = P51 * (1.0 - (DHTL / (ETALPT * CP51 *
$ T51))) ** (GA51
1 / (GA51 - 1.0))
   CALL THERMO (P52, H52, T52, S52, AMW52, CP52, GA52,
$ 1, FAR51, 1)
   TWORK = DHTL
   HPLT = (TWORK * WG51 * WAENG) / .7068
   HPEXT = HPLT - HPLPC - HPHPC
   PCT1 = 0.0
   PCT2 = 1.0
   HPM = (HPEXT - HPACC) * ETAM
   IPAS = 2

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      GO TO 23
3
C *** TWO TURBINE APU
18 CALL THERMO (P41, H41, T41, S41, AMW41, CP41, GA41,
$ 1, FAR41, 0)
  IF (HPM .NE. 0.0) GO TO 19
  RATIO      = (GA41 - 1.0) / GA41
  THWORK     = ETAHPT * CP41 * T41 * (1.0 - ((1.0 /
$ PRHPT) **
1  RATIO))
  DHTH       = THWORK
  H5         = H41 - DHTH
  P5         = P41 / PRHPT
  CALL THERMO (P5, H5, T5, S5, AMW5, CP5, GA5, 1,
$ FAR41, 1)
  P51        = P5 * (1.0 - DPT)
  WG51       = WG41 + 3LHPT
  H51        = (H5 * WG41 + 4B * BLHPT) / WG51
  FAR51      = WF4 / (WG51 - WF4)
  CALL THERMO (P51, H51, T51, S51, AMW51, CP51, GA51,
$ 1, FAR51, 1)
  RATIO      = (GA51 - 1.0) / GA51
  DHTL       = ETALPT * CP51 * T51 * (1.0 - ((1.0 /
$ PRLPT) **
1  RATIO))
  H52        = H51 - DHTL
  P52        = P51 / PRLPT
  CALL THERMO (P52, H52, T52, S52, AMW52, CP52, GA52,
$ 1, FAR51, 1)
  PCT1       = DHTH / (DHTH + DHTL)
  PCT2       = DHTL / (DHTH + DHTL)
  IPAS       = 1
  HPHT       = (THWORK * WG41 * WAENG) / .7068
  HPLT       = (DHTL * WG51 * WAENG) / .7068
  HPEXT      = HPHT - HPHPC + HP_LT - HPLPC
  HPM        = (HPEXT - HPACC) * ETAM
  GO TO 23
19 HPBTU     = ((HPACC + (HPDS / ETAM)) * .7068) /
$ (WG41 * WAENG)
  DHALL      = HPBTU + ((H3 - H22) * WA22 + (H21 - H2)
$ * WA2) / WG41
  DWORKHT    = DHALL * (PCT1) * WG41 * WAENG
  FAR5       = FAR41
  DHTH       = DWORKHT / (WG41 * WAENG)
  H5         = H41 - DHTH
  P5         = P41 * (1.0 - (DHTH / (ETAHPT * CP41 *
$ T41))) ** (GA41
1  / (GA41 - 1.0))
  CALL THERMO (P5, H5, T5, S5, AMW5, CP5, GA5, 1,
$ FAR5, 1)

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```

PRHPT      = P41 / P5
P51        = P5 * (1.0 - DPT)
WG51       = WG41 + BLHPT
H51        = (H5 * WG41 + HB * BLHPT) / WG51
FAR51      = WF4 / (WG51 - WF4)
CALL THERMO (P51, H51, T51, S51, AMW51, CP51, GA51,
$ 1, FAR51, 1)
DWORKLT    = DHALL * (PRLPT / (PR4PT * PRLPT)) * WG51
$ * WAENG
DHTL       = DWORKLT / (WG51 * WAENG)
H52        = H51 - DHTL
P52        = P51 * (1.0 - (DHTL / (ETALPT * CP51 *
$ T51))) ** (GA51
1 / (GA51 - 1.0))
CALL THERMO (P52, H52, T52, S52, AMW52, CP52, GA52,
$ 1, FAR51, 1)
PCT1       = DWORKHT / (DWORKHT + DWORKLT)
PCT2       = DWORKLT / (DWORKHT + DWORKLT)
HPHT       = DWORKHT / .7058
HPLT       = DWORKLT / .7058
HPEXT      = HPHT - HPHPG + HPLT - HPLPG
HPM        = (HPEXT - HPACG) * ETAM
IPAS       = 2
GO TO 23

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```

C
C *** TWO TURBINE APU WITH ONE OF THE TURBINES A POWER
C $ TURBINE
20 CALL THERMO (P41, H41, T41, S41, AMW41, CP41, GA41,
$ 1, FAR41, 1)
RATIO      = (GA41 - 1.0) / GA41
THWORK     = ETAHPT * CP41 * T41 * (1.0 - ((1.0 /
$ PRHPT) **
1 RATIO))
DHTH       = THWORK
H5         = H41 - DHTH
P5         = P41 / PR4PT
CALL THERMO (P5, H5, T5, S5, AMW5, CP5, GA5, 1,
$ FAR41, 1)
HPHT       = (THWORK * WG41 * WAENG) / .7058
HPTT      = HPHT - HPACC - HPHPG - HPLPG
IF (HPTT .GE. 0.0) GO TO 21
HP8TU     = (HPACC * .7058) / (WG41 * WAENG)
DHTH       = HP8TU + (((H3 - 422) * WA22 + (H21 - 42)
$ * WA2) /
1 WG41)
H5         = H41 - DHTH
P5         = P41 * (1.0 - (DHTH / (ETAHPT * CP41 *
$ T41))) ** (GA41
1 / (GA41 - 1.0))
CALL THERMO (P5, H5, T5, S5, AMW5, CP5, GA5, 1,
$ FAR41, 1)

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```

PRHPT      = P41 / P5
PRINT *, "PRESSURE RATIO CALCULATED AS NEEDED FOR
$ HPT"
21 P51      = P5 * (1.0 - DPT)
   WG51     = WG41 + BLHPT
   H51      = (H5 * WG41 + 4B * BLHPT) / WG51
   FAR51    = WF4 / (WG51 - WF4)
   CALL THERMO (P51, H51, T51, S51, AMW51, CP51, GA51,
$ 1, FAR51, 1)
   IF (HPM .NE. 0.0) GO TO 22
   RATIO2    = (GA51 - 1.0) / GA51
   TWORK     = ETALPT * CP51 * T51 * (1.0 - ((1.0 /
$ PRLPT) **
1  RATIO2))
   DHTL      = TWORK
   H52       = H51 - DHTL
   P52       = P51 / PRLPT
   CALL THERMO (P52, H52, T52, S52, AMW52, CP52, GA52,
$ 1, FAR51, 1)
   HPEXT     = (TWORK * WG51 * WAFNG) / .7068
   HPLT      = HPEXT
   HPM       = HPEXT * ETAM
   DWORKHT   = DHTL * WG41 * WAENG
   DWORKLT   = DHTL * WG51 * WAENG
   PCT1      = DWORKHT / (DWORKHT + DWORKLT)
   PCT2      = DWORKLT / (DWORKHT + DWORKLT)
   IPAS      = 1
   GO TO 23
22 DHTL      = ((HPDS / ETAM) * .7058) / (WG51 * WAENG)
   CALL THERMO (P52, H52, T52, S52, AMW52, CP52, GA52,
$ 1, FAR51, 1)
   P52       = P51 * (1.0 - (DHTL / (ETALPT * CP51 *
$ T51))) ** (GA51
1  / (GA51 - 1.0))
   H52       = H51 - DHTL
   TWORK     = DHTL
   HPEXT     = (TWORK * WG51 * WAFNG) / .7068
   HPLT      = HPEXT
   DWORKHT   = DHTL * WG41 * WAENG
   DWORKLT   = DHTL * WG51 * WAENG
   PCT1      = DWORKHT / (DWORKHT + DWORKLT)
   PCT2      = DWORKLT / (DWORKHT + DWORKLT)
   HPM       = HPEXT * ETAM
   PRLPT     = P51 / P52
   IPAS      = 2
   GO TO 23
C
C *** LOW PRESSURE TURBINE OR POWER TURBINE EXIT, WITH
C $      COOLING FLOW,

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C          IF ANY, PLUS STATION 5 CALCULATION.
23 PRLPT      = P51 / P52
   P52        = P51 / PRLPT
   CALL THERMO (P52, H52, T52, S52, AMW52, CP52, GA52,
$ 1, FAR51, 1)
   P53        = P52
   IF (IPAS .EQ. 1) GO TO 27
   IF (P53 .GE. P1) GO TO 27
C          ON 2ND PASS WHEN WORK REQUIRED CAUSES
C          OVEREXPANSION OF LAST
C          TURBINE, ASSUME THE TURBINE EXPANDS ONLY TO
C          ATMOSPHERIC.
$ PRINT *, "P53<P1,LPT OVEREXPANDED, SET P53=P1,
$ RECALC WORK"
   P53        = P52 = P1
   REPRTL     = P51 / P52
   RETIO      = (GA51 - 1.) / GA51
   REWORK     = ETALPT * CP51 * T51 * (1. - ((1. /
$ REPRTL) ** RETIO))
   PRLPT      = REPRTL
   H52        = H51 - REWORK
   HPRE       = (REWORK * WG51 * WAENG) / .7068
   IF (M .GT. 1) GO TO 24
   HPEXT      = HPRE - HPLPC - HPHPC
   HPM        = (HPEXT - HPAC3) * ETAM
   GO TO 26
24 IF (M .GT. 2) GO TO 25
   HPEXT      = HPHT - HPHPC + HPRE - HPLPC
   HPM        = (HPEXT - HPAC3) * ETAM
   PCT2       = HPRE / (HPRE + HPHT)
   GO TO 26
25 HPEXT      = HPRE
   PCT2       = HPRE / (HPHT + HPRE)
   HPLT       = HPEXT
   HPM        = HPEXT * ETAM
26 CALL THERMO (P52, H52, T52, S52, AMW52, CP52, GA52,
$ 1, FAR51, 1)
C          ON 1ST PASS, IF LAST TURBINE NOT
C          OVEREXPANDED,
27 PS6        = P1
C          LAST TURBINE EXIT COOLING CALCULATIONS
   WG53       = WG51 + 3LLPT
   H53        = (H52 * WG51 + H5 * 3LLPT) / WG53
   FAR53      = WF4 / (WG53 - WF4)
   CALL THERMO (P53, H53, T53, S53, AMW53, CP53, GA53,
$ 1, FAR53, 1)
   RTIO53     = (GA53 - 1.) / GA53
   DPE        = (P53 - PS6) / P53
   TS6        = T53
   CALL THERMO (PS6, HS6, TS6, SS6, AMW6, CP6, GA6, 1,
$ FAR53, 0)

```

```

DELNOZ = H53 * (1. - (P1 / P53) ** RTIO53)
V6      = SQRT(2 * G * (DELNOZ) * AJ)
WG6     = WG53
FAR5    = FAR53

```

C

C \*\*\* PERFORMANCE CALCULATIONS

```

THG6    = V6 * WG6 / G
FNQWA   = THG6 / WA2
SFCU    = WF4 * WAENG * 3600 / HPM
FG       = THG6 * WAENG
FN       = FNQWA * WAENG
ETATHM  = HPEXT * 550. / (WF4 * WAENG * HV * AJ)

```

C

C \*\*\* DEFINE OUTPUT PARAMETERS

```

XWA21   = WA21 * WAENG
XWA22   = WA22 * WAENG
XWA3    = WA3 * WAENG
XWG4    = WG4 * WAENG
XWG41   = WG41 * WAENG
XWG51   = WG51 * WAENG
XWG53   = WG53 * WAENG
XWG6    = WG6 * WAENG
XWF4    = WF4 * WAENG * 3600.
XP1     = P1 * PRES
XP2     = P2 * PRES
XP21    = P21 * PRES
XP22    = P22 * PRES
XP3     = P3 * PRES
XP4     = P4 * PRES
XP41    = P41 * PRES
XP5     = P5 * PRES
XP51    = P51 * PRES
XP52    = P52 * PRES
XP53    = P53 * PRES
XPS6    = PS6 * PRES
CF2     = (WA2 * WAENG * SQRT(T2 / T11)) / (P2 /
$ P1)
CF21    = (XWA21 * SQRT(T21 / T11)) / (P21 / P1)
CF22    = (XWA22 * SQRT(T22 / T11)) / (P22 / P1)
CF3     = (XWA3 * SQRT(T3 / T11)) / (P3 / P1)
CF4     = (XWG4 * SQRT(T4 / T11)) / (P4 / P1)
CF41    = (XWG41 * SQRT(T41 / T11)) / (P41 / P1)
CF51    = (XWG51 * SQRT(T51 / T11)) / (P51 / P1)
CF52    = (XWG51 * SQRT(T52 / T11)) / (P52 / P1)
CF53    = (XWG53 * SQRT(T53 / T11)) / (P53 / P1)
CF6     = (XWG6 * SQRT(TS6 / T11)) / (PS6 / P1)
CFF     = XWF4 / ((P4 / P1) * SQRT(T4 / T11))
HPMAMB  = (HPEXT * SQRT(T1 / 518.67)) / (P1 / 1.0)
THETA1  = T1 / T11

```

```

THETA2      = T2 / T11
THETA3      = T3 / T11
THETA21     = T21 / T11
THETA22     = T22 / T11
THETA4      = T4 / T11
THETA41     = T41 / T11
THETA5      = T5 / T11
THETA51     = T51 / T11
THETA52     = T52 / T11
THETA53     = T53 / T11
THETA6      = TS6 / T11
DELTA1      = P1 / P1
DELTA2      = P2 / P1
DELTA21     = P21 / P1
DELTA22     = P22 / P1
DELTA3      = P3 / P1
DELTA4      = P4 / P1
DELTA41     = P41 / P1
DELTA5      = P5 / P1
DELTA51     = P51 / P1
DELTA52     = P52 / P1
DELTA53     = P53 / P1
DELTA6      = PS6 / P1
T1          = T1 - 459.67
T2          = T2 - 459.67
T21         = T21 - 459.67
T22         = T22 - 459.67
T8          = T8 - 459.67
T3          = T3 - 459.67
T4          = T4 - 459.67
T41         = T41 - 459.67
T5          = T5 - 459.67
T51         = T51 - 459.67
T52         = T52 - 459.67
T53         = T53 - 459.67
TS6         = TS6 - 459.67

```

C

```

C *** WRITE OUT THE OUTPUT PAGE
  IF (PRES .GT. 1.0) IP = 2
  IF (ITITLE .EQ. 0) GO TO 28
  WRITE (6, 141) AWORD (IP)
  GO TO 29
28  WRITE (6, 142) AWORD (IP)
29  ITITLE = 0
    WRITE (6, 143) XP1, T1, H1, DELTA1, THETA1
    IF (PRLPC .LE. 1.0) GO TO 30
    WRITE (6, 144) XP2, T2, H2, WAENG, CF2, DELTA2,
$ THETA2, ETALPC,
1  PRLPC, DPIN
    WRITE (6, 145) XP21, T21, H21, XWA21, CF21,
$ DELTA21, THETA21,

```

```

1   DPC
30  IF (PRHPC .LE. 1.0) GO TO 31
    WRITE (6, 146) XP22, T22, H22, XWA22, CF22,
$   DELTA22, THETA22,
1   ETAPPC, PRHPC
31  IF (PRHPC .LE. 1.0) IB = 1
    WRITE (6, 147) ANUM (IB), XP3, T3, H3, XWA3, CF3,
$   DELTA3,
1   THETA3, PROA
    WRITE (6, 148) XP4, T4, H4, XWA4, CF4, DELTA4,
$   THETA4, FAR4,
1   ETAB, DPB
    IF (M .EQ. 1) GO TO 32
    WRITE (6, 149) XP41, T41, H41, XWA41, CF41,
$   DELTA41, THETA41,
1   FAR41, ETAPPT, PRHPT
    WRITE (6, 150) XP5, T5, H5, XWA5, CF5, DELTA5,
$   THETA5, FAR5,
1   DPT
    WRITE (6, 151) XP51, T51, H51, XWA51, CF51,
$   DELTA51, THETA51,
1   FAR51
32  IF (M .EQ. 1) IN = 1
    WRITE (6, 152) ANUM (IN), XP51, T51, H51, XWA51,
$   CF51, DELTA51,
1   THETA51, FAR51, ETALPT, PR_LPT
    WRITE (6, 153) ANUM (IN), XP52, T52, H52, XWA52,
$   CF52, DELTA52,
1   THETA52, FAR52
    WRITE (6, 154) ANUM (IN), XP53, T53, H53, XWA53,
$   CF53, DELTA53,
1   THETA53, FAR53
    WRITE (6, 155) XPS3, TS3, HS6, XWA6, CF6, DELTA6,
$   THETA6, FAR6,
1   DPE
    WRITE (6, 156) ALTP
    WRITE (6, 157) CS
    WRITE (6, 158) DELTAMB
    WRITE (6, 159) DELPAMB
    WRITE (6, 160) N
    WRITE (6, 161) M
    WRITE (6, 162) HPDS
    WRITE (6, 163) HPEXT
    WRITE (6, 164) HPMAMB
    WRITE (6, 165) HPM
    WRITE (6, 166) HPA3C
    WRITE (6, 167) HPL3C
    WRITE (6, 168) HPHPC
    WRITE (6, 169) XWF4

```

```

WRITE (6, 170) CFF
WRITE (6, 171) HV
WRITE (6, 172) WLPD
WRITE (6, 173) LCSL
WRITE (6, 174) WHPD
WRITE (6, 175) HCSL
WRITE (6, 176) PCT1
WRITE (6, 177) HPHT
WRITE (6, 178) PCT2
WRITE (6, 179) HPLT
IF (M.EQ. 4) WRITE (6, 180)
WRITE (6, 181) FN
WRITE (6, 182) FG
WRITE (6, 183) FNQ4A
WRITE (6, 184) ETAT44
WRITE (6, 185) V6
WRITE (6, 186) SFCJ
IF (IPAS.NE. 2) GO TO 33
DPE      = 0.0
PRHPT    = 1.0
PRLPT    = 1.0
HV       = 18400.0
GO TO 1
33 T1      = T1 + 459.67
   T2      = T2 + 459.67
   T21     = T21 + 453.57
   T22     = T22 + 453.57
   TB      = TB + 459.67
   T3      = T3 + 459.67
   T4      = T4 + 459.67
GO TO 11
C
C *** ERROR STATEMENTS
34 WRITE (6, 187)
   GO TO 5
35 WRITE (6, 188) PRLPD, PRHPD, ETALPD, ETAMPD
   STOP
36 WRITE (6, 189) WF4DS, T4, ETA9
   STOP
37 WRITE (6, 190) PRHPT, PRLPT, ETAHPT, ETALPT
   STOP

```

C

C

```

100 FORMAT ( / / , 33X, 48HTHIS PROGRAM WAS DEVELOPED
$ BY COMPONENT
1S BRANCH , 23HTURBINE ENGINE DIVISION, / , 34X,
$ 26HMODIFIED BY PO
2WER DIVISION, 42H U.S. AIR FORCE AERO PROPULSION
3 LABORATORY )

```

```

101 FORMAT ( 1H1, 20X, 18H***INPUT VALUES*** )
102 FORMAT ( 11A6 )
103 FORMAT ( 1H1 / 1H , 40X, 11A5 )
104 FORMAT ( 1H0, 20X, 18H***INPUT VALUES*** )
105 FORMAT ( / / , 5X, 16HALTITUDE (FT) = , F3.0 )
106 FORMAT ( 5X, 17HPRESSURE (PSI) = , F6.3 )
107 FORMAT ( 5X, 29HDELTA TEMP FROM 1962 ATMOS = , F8.5
$ )
108 FORMAT ( / , 5X, 18HBEGIN INDICATOR = , I1 )
109 FORMAT ( 5X, 16HEND INDICATOR = , I1 )
110 FORMAT ( / , 5X, 23HNO OF COMPRESSOR STAGES = , I1
$ )
111 FORMAT ( 5X, 23HNO OF TURBINE STAGES = , I1 )
112 FORMAT ( / , 5X, 74FLOW = , F10.5 )
113 FORMAT ( 5X, 11HMECH EFF = , F8.5 )
114 FORMAT ( 5X, 29HHPACC EXTRACTED FOR ACCESS = , F4.2
$ )
115 FORMAT ( 5X, 21HDESIGN SHAFT POWER = , F10.4 )
116 FORMAT ( / , 5X, 24HINLET JUCT PRESS LOSS = , F4.2
$ )
117 FORMAT ( 5X, 18HLPC PRESS RATIO = , F5.3 )
118 FORMAT ( 5X, 10HLPC EFF = , F8.5 )
119 FORMAT ( 5X, 19HLPC SEAL LEAKAGE = , F3.1 )
120 FORMAT ( 5X, 27HLPC BLEED, TO BE USED LATER )
121 FORMAT ( / , 5X, 24HINTER-COMP PRESS LOSS = , F4.2
$ )
122 FORMAT ( 5X, 24HBLEED DUCT PRESS LOSS = , F6.3 )
123 FORMAT ( / , 5X, 18HHPC PRESS RATIO = , F5.3 )
124 FORMAT ( 5X, 10HHPC EFF = , F8.5 )
125 FORMAT ( 5X, 19HHPC SEAL LEAKAGE = , F4.2 )
126 FORMAT ( / , 5X, 23HMAIN COMP PRESS LOSS = , F8.5
$ )
127 FORMAT ( 5X, 22HMAIN COMBUSTION EFF = , F8.5 )
128 FORMAT ( 5X, 27HDESIGN FUEL FLOW (LB/HR) = , F6.2 )
129 FORMAT ( 5X, 45HMAIN COMB FUEL HEATING VALUE AT T4
$ FOR JP4 = ,
1 F6.0 )
130 FORMAT ( 5X, 39HCOMB DISCHARGE TEMP (DEGREE
$ RANKINE) = , F7.2 )
131 FORMAT ( 5X, 39HHPT INLET NOZ COOLING/HPC INLET
$ FLOW = , F8.5 )
132 FORMAT ( / , 5X, 18HHPT PRESS RATIO = , F5.3 )
133 FORMAT ( 5X, 10HHPT EFF = , F5.2 )
134 FORMAT ( 5X, 30HTURB COOLING/HPC INLET FLOW = ,
$ F8.5 )
135 FORMAT ( / , 5X, 35HINTER TURB PRESS LOSS (P5-P51)
$ /P5 = , F5.2
1 )
136 FORMAT ( / , 5X, 13HLPT PRESS RATIO = , F5.3 )
137 FORMAT ( 5X, 10HLPT EFF = , F8.5 )

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```

138 FORMAT ( 5X, 39HEXHAUST DUCT PPESS LOSS (P53-P1)/
$ P53 = , F3.1 )
139 FORMAT ( 5X, 29HLPT COOLING/4PC INLET FLOW = , F8.5
$ )
140 FORMAT ( 1H1, 52X, 19H***OUTPUT VALUES*** )
141 FORMAT ( 1H0, 9X, 21HSTATION PRESSURE-, A3, 2X,
$ 29HTEMP-DEG.
1F ENTHALPY FLOW, 3X, 42HGOR FLOW DELTA
$ THETA FUEL/AIR
2 EFF, 2X, 18HPRESS RATIO DEL P )
142 FORMAT ( 1H1, 9X, 21HSTATION PRESSURE-, A3, 2X,
$ 29HTEMP-DEG.
1F ENTHALPY FLOW, 3X, 42HGOR FLOW DELTA
$ THETA FUEL/AIR
2 EFF, 2X, 18HPRESS RATIO DEL P )
143 FORMAT ( 1H , 6X, 9HAMBIENT , 9X, F8.3, 5X, F8.2,
$ 3X, F8.2,
1 21X, F7.3, 2X, F7.3 )
144 FORMAT ( 1H , 6X, 13HLP COMP INLET, 4X, F8.3, 5X,
$ F8.2, 3X,
1 F8.2, 2X, F7.3, 3X, F7.3, 2X, F7.3, 2X, F7.3, 12X,
$ F7.5, 2X,
2 F7.3, 2X, F7.5 )
145 FORMAT ( 1H , 6X, 12HLP COMP EXIT, 5X, F8.3, 5X,
$ F8.2, 3X, F8.2,
1 2X, F7.3, 3X, F7.3, 2X, F7.3, 2X, F7.3, 30X, F7.5
$ )
146 FORMAT ( 1H , 6X, 13HHP COMP INLET, 4X, F8.3, 5X,
$ F8.2, 3X,
1 F8.2, 2X, F7.3, 3X, F7.3, 2X, F7.3, 2X, F7.3, 12X,
$ F7.5, 2X,
2 F7.3 )
147 FORMAT ( 1H , 6X, A3, 10HCOMP EXIT/, / 1H , 8X,
$ 12HBURNER INLET
1, 3X, F8.3, 5X, F8.2, 3X, F8.2, 2X, F7.3, 3X, F7.3,
$ 2X, F7.3, 2X,
2F7.3, 21X, F7.3 )
148 FORMAT ( 1H , 6X, 11HBURNER EXIT, 6X, F8.3, 5X,
$ F8.2, 3X, F8.2,
1 2X, F7.3, 3X, F7.3, 2X, F7.3, 2X, F7.3, 2X, F8.5,
$ 2X, F7.5,
2 11X, F7.5 )
149 FORMAT ( 1H , 6X, 12HTURB 1 INLET, 5X, F8.3, 5X,
$ F8.2, 3X, F8.2,
1 2X, F7.3, 3X, F7.3, 2X, F7.3, 2X, F7.3, 2X, F8.5,
$ 2X, F7.5, 2X,
2 F7.3 )
150 FORMAT ( 1H , 6X, 11HTURB 1 EXIT, 6X, F8.3, 5X,
$ F8.2, 3X, F8.2,
1 2X, F7.3, 3X, F7.3, 2X, F7.3, 2X, F7.3, 2X, F8.5,
$ 2(X, F7.5 )

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151  FORMAT ( 1H , 6X, 11HTURB 1 EXIT, / 1H, 8X,
      $ 12HPLUS COOLING,
      1 3X, F8.3, 5X, F8.2, 3X, F8.2, 2X, F7.3, 3X, F7.3,
      $ 2X, F7.3, 2X,
      2 F7.3, 2X, F8.5 )
152  FORMAT ( 1H , 6X, 41TURB, A3, 51INLET, 5X, F8.3,
      $ 5X, F8.2, 3X,
      1 F8.2, 2X, F7.3, 3X, F7.3, 2X, F7.3, 2X, F7.3, 2X,
      $ F8.5, 2X,
      2 F7.5, 2X, F7.3 )
153  FORMAT ( 1H , 6X, 4HTURB, A3, 51EXIT , 5X, F8.3,
      $ 5X, F8.2, 3X,
      1 F8.2, 2X, F7.3, 3X, F7.3, 2X, F7.3, 2X, F7.3, 2X,
      $ F8.5 )
154  FORMAT ( 1H , 6X, 41TURB, A3, 41EXIT, / 1H , 8X,
      $ 12HPLUS COOLIN
      1G, 3X, F8.3, 5X, F8.2, 3X, F8.2, 2X, F7.3, 3X, F7.3,
      $ 2X, F7.3, 2X,
      2F7.3, 2X, F8.5 )
155  FORMAT ( 1H , 6X, 17HEXHT/STATIC COND , F8.3, 5X,
      $ F8.2, 3X,
      1 F8.2, 2X, F7.3, 3X, F7.3, 2X, F7.3, 2X, F7.3, 2X,
      $ F8.5, 2X,
      2 F7.5 )
156  FORMAT ( / / , 5X, 16HALTITUDE (FT) = , F3.0 )
157  FORMAT ( 5X, 17HSPEED OF SOUND = , F7.2 )
158  FORMAT ( 5X, 29HDELTA TEMP FROM 1962 ATMOS = , F5.2
      $ )
159  FORMAT ( 5X, 30HDELTA PRESS FROM 1962 PRESS = ,
      $ F4.2 )
160  FORMAT ( / , 5X, 20HNO OF COMP STAGES = , I1 )
161  FORMAT ( 5X, 20HNO OF TURB STAGES = , I1 )
162  FORMAT ( / , 5X, 18HDESIGN SHAFT HP = , F10.4 )
163  FORMAT ( 5X, 16HSHP EXTRACTED = , F10.5 )
164  FORMAT ( 5X, 28HSHP EXTRACTED, COR FOR SL = , F10.3
      $ )
165  FORMAT ( 5X, 34HSHP EXTRACTED, COR FOR MECH EFF = ,
      $ F10.5 )
166  FORMAT ( 5X, 31HHP EXTRACTED FOR ACCESSORIES = ,
      $ F5.3 )
167  FORMAT ( 5X, 20HHP NEEDED FOR LPC = , F7.3 )
168  FORMAT ( 5X, 20HHP NEEDED FOR HPC = , F15.5 )
169  FORMAT ( / , 5X, 23HCALCULATED FUEL FLOW = , F9.4
      $ )
170  FORMAT ( 5X, 17HFUEL FLOW COEF = , F15.5 )
171  FORMAT ( 5X, 45HMAIN COMB FUEL HEATING VALUE AT T4
      $ FOR JPL = ,
      1 F8.1 )
172  FORMAT ( / , 5X, 23HWORK OF LPC (BTU/LB) = , F6.3
      $ )

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```

173 FORMAT ( 5X, 33HLPC SEAL LEAKAGE FLOW FRACTION = ,
$ F7.5 )
174 FORMAT ( / , 5X, 23HWORK OF HPC (BTU/LB) = , F7.3
$ )
175 FORMAT ( 5X, 33HHPC SEAL LEAKAGE FLOW FRACTION = ,
$ F8.5 )
176 FORMAT ( / , 5X, 13HHPT WORK PERCENT = , F5.3 )
177 FORMAT ( 5X, 20HHORSEPOWER OF HPT = , F15.5 )
178 FORMAT ( / , 5X, 13HLPT WORK PERCENT = , F5.3 )
179 FORMAT ( 5X, 20HHORSEPOWER OF LPT = , F15.5 )
180 FORMAT ( 5X, 32HTHIS IS ACTUALLY A POWER TURBINE )
181 FORMAT ( / , 5X, 13HNET THRUST = , F10.5 )
182 FORMAT ( 5X, 15HGROSS THRUST = , F10.5 )
183 FORMAT ( 5X, 28HNET THRUST/ENGINE AIRFLOW = , F10.5
$ )
184 FORMAT ( 5X, 14HTHERMAL EFF = , F8.5 )
185 FORMAT ( 5X, 24HEXHAUST EXIT VELOCITY = , 19X, F9.3
$ )
186 FORMAT ( 5X, 41HENGINE UNINSTALLED SFC (LB FUEL/HR-
$ HP) = , F8.4
1 )
187 FORMAT ( 1H0, 12HLPC NOT USED )
188 FORMAT ( 1H0, 44H*** ERROR IN COMPRESSOR INPUT
$ PARAMETERS ***,
1 / , 5X, 8HPR LPC = , F7.3, 4X, 8HPRHPC = , F7.3,
$ 4X, 9HETALPC =
2, F9.5, 4X, 9HETAHPC = , F9.5 )
189 FORMAT ( 1H0, 43H*** ERROR IN COMBUSTOR INPUT
$ PARAMETERS ***, /
1 , 5X, 8HWF4DS = , F6.2, 4X, 5HT4 = , F7.2, 4X,
$ 7HETA8 = , F8.5
2 )
190 FORMAT ( 1H0, 41H*** ERROR IN TURBINE INPUT
$ PARAMETERS ***, / ,
1 5X, 8HPRHPT = , F5.3, 4X, 7HPR LPT = , F5.3, 5X,
$ 9HETAHPT = ,
2 F5.2, 4X, 9HETALPT = , F5.2 )

```

C

END

```

      SUBROUTINE ATMOS (HFT, TM, DELTA)
      THIS IS A SUBROUTINE TO COMPUTE CERTAIN ELEMENTS OF THE
      $      1962
      U.S. STANDARD ATMOSPHERE UP TO 99 KILOMETERS.
      CALLING SEQUENCE...

      CALL ATMOS (HFT, TM, DELTA)
      HFT = GEOPOTENTIAL ALTITUDE (FEET)
      TM = MOLECULAR SCALE TEMPERATURE (DEGREES
      $      RANKINE)
      DELTA = RATIO OF PRESSURE TO THAT AT SEA LEVEL

      ALL DATA AND FUNDAMENTAL CONSTANTS ARE IN THE METRIC
      $      SYSTEM AS
      THESE QUANTITIES ARE DEFINED AS EXACT IN THIS SYSTEM.

      THE RADIUS OF THE EARTH (REFT59) IS THE VALUE
      $      ASSOCIATED WITH THE
      1959 ARDC ATMOSPHERE SO THAT PROGRAMS CURRENTLY USING
      $      THE LIBRARY
      ROUTINE WILL NOT REQUIRE ALTERATION TO USE THIS
      $      ROUTINE.
      DIMENSION ALM (10), DELTAB (10), HB (10), TMB (10)
      DATA (HB(I), I=1, 10) / - 5., 0., 11., 20.,
      $ 32., 47., 52.,
      1 61., 79., 88.743 /
      DATA (TMB(I), I=1, 10) / 320.65, 288.15, 216.65,
      $ 216.65,
      1 228.65, 270.65, 270.65, 252.65, 180.65, 180.65 /
      DATA (DELTAB(I), I=1, 10) / 1.75363, 1.,
      $ 2.23361E - 01,
      1 5.40328E - 02, 8.56663E - 03, 1.09455E - 03,
      $ 5.82289E - 04,
      2 1.79718E - 04, 1.0241E - 05, 1.5223E - 06 /
      DATA (ALM(I), I=1, 10) / - 5.5, - 6.5, 0., 1.,
      $ 2.8, 0.,
      1 - 2., - 4., 0., 0. /
      DATA REFT59 / 2.0955531E07 /, GZ / 9.80665 /, AMZ
      $ / 28.9644 /,
      1 RSTAR / 8.31432 /, FTTOKM / 3.048E - 04 /
      CONVERT GEOPOTENTIAL ALTITUDE TO GEOMETRIC ALTITUDE
      ZFT = HFT * REFT59 / (REFT59 - HFT)
      CONVERT HFT AND ZFT TO KILOMETERS
      Z = FTTOKM * ZFT
      H = FTTOKM * HFT
      IF (H .LT. -5.0 .OR. Z .GT. 30.0) GO TO 6
      DO 1 M = 1, 10
      IF (H - HB(M)) 2, 3, 1
      1 CONTINUE

```

```

      GO TO 6
2   M      = M - 1
3   DELH   = H - HB(M)
      IF (ALH(M) .EQ. 0.0) GO TO 4
      TMK   = TMB(M) + ALH(M) * DELH
J   GRADIENT IS NON ZERO, PAGE 10, EQUATION I.2.10-(3)
      DELTA = DELTAB(M) * ((TMB(M) / TMK) ** (GZ * AMZ
      $ / (RSTAR *
      1   ALH(M))))
      GO TO 5
4   TMK     = TMB(M)
C   GRADIENT IS ZERO, PAGE 10, EQUATION I.2.10-(4)
      DELTA = DELTAB(M) * EXP( - GZ * AMZ * DELH /
      $ (RSTAR *
      1   TMB(M)))
C   CONVERSION TO ENGLISH UNITS
5   TM      = 1.8 * TMK
6   RETURN
      END

```

```

      SUBROUTINE PROCOM (FARX, TEX, CSEX, AKFX, CPEX,
      $ REX, PHI, HEX)
C *** CALCULATES THERMO GAS PROPERTIES, AIR OR JP-4/AIR
C   $ MIXTURE
      COMMON /WPAFR/ ICOJNT
      IF (FARX .LE. 0.057623) GO TO 1
      FARX      = 0.067623
      WRITE (6, 100)
1     IF (TEX .GE. 300.) GO TO 2
      TEX      = 300.
      IF (ICOJNT .GT. 1) GO TO 2
      WRITE (6, 101)
2     IF (TEX .LE. 4000.) GO TO 3
      TEX      = 4000.
      WRITE (6, 102)
3     IF (FARX .GE. 0.0) GO TO 4
      FARX      = 0.0
      WRITE (6, 103)
C   AIR PATH
4     CPA      = ((((((1.0115540E - 25 * TEX - 1.4526770E
      $ - 21) * TEX
1     + 7.6215767E - 18) * TEX - 1.5128259E - 14) * TEX
      $ - 6.7178376E
2     - 12) * TEX + 6.5519486E - 08) * TEX - 5.1536879E
      $ - 05) * TEX +
3     2.5020051E - 01
      HEA      = ((((((1.2644425E - 25 * TEX -
      $ 2.0752522E - 22) * TEX
1     + 1.2702630E - 18) * TEX - 3.0256518E - 15) * TEX
      $ - 1.6794594E
2     - 12) * TEX + 2.1839825E - 08) * TEX - 2.5769440E
      $ - 05) * TEX +
3     2.5120051E - 01) * TEX - 1.7558886E + 00
      SEA      = + 2.5020051E - 01 * ALOG(TEX) +
      $ ((((((1.4450767E -
1     25 * TEX - 2.4211298E - 22) * TEX + 1.5243153E -
      $ 18) * TEX -
2     3.7820648E - 15) * TEX - 2.232790E - 12) * TEX +
      $ 3.2759743E -
3     08) * TEX - 5.1576879E - 05) * TEX + 4.543230E -
      $ 02
      IF (FARX .EQ. 0.0) GO TO 5
C   FUEL/AIR PATH
      CPF      = ((((((7.2678710E - 25 * TEX - 1.3335668E
      $ - 20) * TEX
1     + 1.1212913E - 16) * TEX - 4.2051104E - 13) * TEX
      $ + 9.9686793E
2     - 10) * TEX - 1.3771901E - 06) * TEX + 1.2258630E
      $ - 03) * TEX +

```

```

3 7.3816638E - 02
HEF = ((((((9.0848388E - 25 * TEX -
$ 1.9050949E - 21) * TEX
1 + 1.7021525E - 17) * TEX - 8.4102208E - 14) * TEX
$ + 2.4921698E
2 - 10) * TEX - 4.5906332E - 07) * TEX + 6.1293150E
$ - 04) * TEX +
3 7.3816638E - 02) * TEX + 3.0581530E + 01
SIF = + 7.3816638E - 02 * ALOG(TEX) +
$ ((((((1.0382670E -
1 25 * TEX - 2.2226118E - 21) * TEX + 2.0425826E -
$ 17) * TEX -
2 1.0512776E - 13) * TEX + 3.3228928E - 10) * TEX -
$ 6.8659505E -
3 07) * TEX + 1.2258630E - 03) * TEX + 6.483398E -
$ 01
5 CPEX = (CPA + FARX * CPF) / (1. + FARX)
HEX = (HEA + FARX * HEF) / (1. + FARX)
PHI = (SEA + FARX * SEF) / (1. + FARX)
AMW = 28.97 - .946186 * FARX
REX = 1.986375 / AMW
AKEX = CPEX / (CPEX - REX)
CSEX = SQRT(AKEX * REX * TEX * 25031.37)
RETURN

```

C

```

100 FORMAT ( 1H0, 63HINPUT FUEL-AIR RATIO ABOVE LIMITS,
$ IT HAS BEEN
1RESETTO 0.067623, 6H$$$$$$ )
101 FORMAT ( 1H0, 35HPRJCOM INPUT TEMPERATURE BELOW
3 300., 6H$$$$$$
1 )
102 FORMAT ( 1H0, 36HPRJCOM INPUT TEMPERATURE ABOVE
$ 4000., 6H$$$$$$
1 )
103 FORMAT ( 1H0, 38HPRJCOM INPUT FUEL-AIR RATIO BELOW
$ ZERO,
1 6H$$$$$$ )

```

C

END

```

      SUBROUTINE THERMO (PX, HX, TX, SX, AMX, CPT, GA, L,
$ FAR, K)
C *** THERMODYNAMIC PROPERTIES BASED ON PROCOM
      COMMON /WPAFB/ ICOUNT
      ICOUNT      = 1
      FX          = 0.
      IF (L.EQ. 1) FX = FAR
      IF (K.EQ. 1) GO TO 1
      CALL PROCOM (FX, TX, CS, AK, CP, R, PHI, HX)
      GO TO 3
1     TX          = 4. * HX
      DO 2 I      = 1, 15
      CALL PROCOM (FX, TX, CS, AK, CP, R, PHI, H)
      ICOUNT      = ICOUNT + 1
      DELH        = HX - H
      IF (ABS(DELH) .LE. 0.00001 * TX) GO TO 3
2     TX          = TX + 4. * DELH
      WRITE (6, 100)
3     SX          = PHI - R * ALOG(PX)
      AMX         = 1.986375 / R
      CPT         = CP
      GA          = AK
      RETURN
C
100  FORMAT ( 31HNO CONVERGENCE IN THERMO$$$$$ )
C
      END

```

```

SUBROUTINE COMB (PIN, TOJT, HIN, ETAB, DPB, POUT,
$ HOUT, SOUT,
1 FAROUT, HV)
C *** COMPUTES STOICHIOMETRIC TEMPERATURE IN COMBUSTOR - IF
C $ HEATING
C $ VALUE FOR FUEL AND W4DS ARE NOT INPUT, T4, ETAB,
C $ DPB ARE INPUT.
    DIMENSION X (9)
    X(2) = 0.0
    X(3) = 0.0
    POUT = PIN * (1.0 - DPB)
    HV = ((((( - .4594317E - 19 * TOUT) -
$ .2034116E - 15) *
1 TOUT + .2783643E - 11) * TOJT + .2051501E - 07) *
$ TOUT -
2 .2453116E - 03) * TOUT - .9433296E - 01) * TOUT +
$ .1845537E +
3 05
    CALL THERMO (POUT, HOUTA, TOJT, X1, X2, X3, X4, 0,
$ 0.0, 0)
    FAROUT = (HOUTA - HIN) / ((HV * ETAB) - (HOUTA -
$ HIN))
    FARS = FAROUT
    CALL THERMO (POUT, HOUT, TOUT, SOUT, Y1, Y2, Y3, 1,
$ FAROUT, 0)
1 DFLFAR = (FARS - FAROUT) / FAROUT
    CALL AFQUIP (X, TOUT, DFLFAR, 0., 15., .0001, .95,
$ TNEW, ICON)
    IF (ICON - 2) 2, 4, 3
2 TOUT = TNEW
    HV = ((((( - .4594317E - 19 * TOUT) -
$ .2034116E - 15) *
1 TOUT + .2783643E - 11) * TOUT + .2051501E - 07) *
$ TOUT -
2 .2453116E - 03) * TOUT - .9433296E - 01) * TOUT +
$ .1845537E +
3 05
    CALL THERMO (POUT, HOUTA, TOUT, X1, X2, X3, X4, 0,
$ 0.0, 0)
    FAROUT = (HOUTA - HIN) / ((HV * ETAB) - (HOUTA -
$ HIN))
    GO TO 1
3 WRITE (6, 100)
4 CALL THERMO (POUT, HOUT, TOUT, SOUT, X1, X2, X3, 1,
$ FAROUT, 0)
    RETURN
C
100 FORMAT ( 46H STOICHIOMETRIC TEMP WILL NOT CONVERGE
$ IN COMB )

```

3

END

```

SUBROUTINE COMB2 (PIN, TOUT, HIN, ETAB, DPB, POUT,
$ HOUT, SOUT,
1 FAR4, HV)
C *** SIMILAR TO COMB - HEATING VALJE FOR FUEL IS OPTIONAL,
C USER MUST INPUT T4, ETAB, DPB, W=4DS.
DIMENSION X (9)
X(2) = 0.0
X(3) = 0.0
POUT = PIN * (1.0 - DPB)
1 CALL THERMO (POUT, HOUTA, TOJT, X1, X2, X3, X4, 0,
$ 0.0, 0)
FAROUT = (HOUTA - HIN) / ((HV * ETAB) - (HOUTA -
$ HIN))
FARS = FAROUT
DELFAR = (FAR4 - FARS) / FAR4
DIR = SQRT(FAR4 / FARS)
CALL AFQUIP (X, TOUT, DELFAR, 0., 20., .0001, DIR,
$ TNEW, ICON)
IF (ICON - 2) 2, 4, 3
2 TOUT = TNEW
GO TO 1
3 WRITE (6, 100)
4 CALL THERMO (POUT, HOUT, TOUT, SOUT, X1, X2, X3, 1,
$ FAR4, 0)
RETURN
C
100 FORMAT ( 47H STOICHIOMETRIC TEMP WILL NOT CONVERGE
$ IN COMB2 )
C
END

```

```

      SUBROUTINE AFQUIR (X, AIND, DEPEND, ANS, AJ, TOL,
$ DIR, ANEW,
1  ICON)
C *** QUADRATIC CONVERGENCE ROUTINE FOR INTERPOLATION
C X(1)=NAME OF ARRAY TO USE
C AIND=INDEPENDANT VARIABLE
C DEPEND= DEPENDANT VARIABLE
C ANS=ANSWER UPON WHICH TO CONVERGE
C AJ=MAX NUMBER OF TRYs
C TOL=PERCENT TOLERANCE FOR CONVERGENCE
C DIR=DIRECTION AND PERCENTAGE FOR FIRST GUESS
C ANEW=CALCULATED VALUE OF NEXT TRY AT INDEPENDANT VARIABLE
C ICON=CONTROL  =1 GO THRU LOOP AGAIN
C               =2 YOU HAVE REACHED THE ANSWER
C               =3 COUNTER HAS HIT LIMITS
C X(2)=COUNTER STORAGE
C X(3)=CHOOSES METHOD OF CONVERGENCE
C X(4)=THIRD DEPEND VAR
C X(5)=THIRD IND VAR
C X(6)=SECOND DEPEND VAR
C X(7)=SECOND IND VAR
C X(8)=FIRST DEPEND VAR
C X(9)=FIRST IND VAR
C X(3) MUST BE ZERO UPON FIRST ENTRY TO ROUTINE
C
      DIMENSION X (9)
      Y          = 0.
      IF (ANS .EQ. 0) GO TO 1
      DEP        = DEPEND - ANS
      TOLANS     = TOL * ANS
      GO TO 2
1  DEP          = DEPEND
      TOLANS     = TOL
2  IF (ABS(DEP) .LE. TOLANS) GO TO 3
      IF (X(2) - AJ) 5, 5, 5
3  ANEW         = AIND
      X(2)       = 0.
      ICON       = 2
      RETURN
4  ANEW         = Y
      X(2)       = X(2) + 1.
      ICON       = 1
      RETURN
5  ANEW         = Y
      X(2)       = 0.
      ICON       = 3
      RETURN
6  IF (X(3) .GT. 0) GO TO 1
C *** FIRST GUESS USING DIR

```

```

7  X(3)      = 1.
   X(8)      = DEP
   X(9)      = AIND
   IF (AIND) 8, 9, 8
8  Y         = DIR * AIND
   GO TO 4
9  Y         = DIP
   GO TO 4
10 IF (X(3) - 1.) 11, 11, 12
C *** LINEAR GUESS
11 X(3)      = 2.
   X(6)      = DEP
   X(7)      = AIND
   IF (X(8) .EQ. X(6) .OR. X(9) .EQ. X(7)) GO TO 7
   A         = (X(9) - X(7)) / (X(8) - X(6))
   Y         = X(9) - A * X(8)
   IF (ABS(10. * X(9)) - ABS(Y)) 7, 7, 4
C *** QUADRATIC GUESS
12 X(4)      = DEP
   X(5)      = AIND
   IF (X(7) .EQ. X(5) .AND. X(6) .EQ. X(4)) GO TO 7
   IF (X(7) .NE. X(5) .AND. X(6) .NE. X(4)) GO TO 13
   GO TO 11
13 IF (X(9) .EQ. X(5) .AND. X(8) .EQ. X(4)) GO TO 14
   IF (X(9) .NE. X(5) .AND. X(8) .NE. X(4)) GO TO 15
   X(9)      = X(7)
   X(8)      = X(6)
   GO TO 11
14 X(9)      = X(7)
   X(8)      = X(6)
   X(3)      = 1.
   IF (X(9)) 8, 9, 8
15 F         = (X(6) - X(4)) / (X(7) - X(5))
   A         = (X(8) - X(4) - F * (X(9) - X(5))) /
$ ((X(9) - X(7)) *
1  (X(9) - X(5)))
   B         = F - A * (X(5) + X(7))
   C         = X(4) + X(5) * (A * X(7) - F)
   IF (A .EQ. 0 .AND. B .EQ. 0) GO TO 5
   IF (A .NE. 0 .AND. B .NE. 0) GO TO 16
   IF (A .NE. C .AND. B .NE. 0) GO TO 18
   Y         = - C / B
   GO TO 27
16 IF (C .NE. 0.0) GO TO 17
   Y         = 0.
   GO TO 27
17 G         = - C / A
   IF (G .LE. 0.0) GO TO 5
   Y         = SQRT(G)
   YY        = - SQRT(G)

```

```

      GO TO 22
18  IF (C .NE. 0.0) GO TO 19
      Y      = - B / A
      YY     = 0.
      GO TO 22
19  D      = 4. * A * C / 3 ** 2
      IF (1. - D) 11, 20, 21
20  Y      = - B / (2. * A)
      GO TO 27
21  E      = SQRT(1. - D)
      Y      = (- B / (2. * A)) * (1. + E)
      YY     = (- B / (2. * A)) * (1. - E)
22  J      = 4
      DO 23 I = 6, 8, ?
      IF (ABS(X(4)) .LE. ABS(X(I))) GO TO 23
      J      = I
23  CONTINUE
      K      = J + 1
      IF ((X(K)-Y)*(X(K)-YY) .LE. J.0) GO TO 24
      IF (ABS(X(K)-Y) .LE. ABS(X(K)-YY)) GO TO 27
      Y      = YY
      GO TO 27
24  IF (J .GE. 6) GO TO 25
      JJ     = J + 2
      KK     = K + 2
      GO TO 26
25  JJ     = J - 2
      KK     = K - 2
26  SLOPE   = (X(KK) - X(K)) / (X(JJ) - X(J))
      IF (SLOPE*X(J)*(X(K)-Y) .GT. J.0) GO TO 27
      Y      = YY
27  X(9)    = X(7)
      X(8)    = X(6)
      X(7)    = X(5)
      X(6)    = X(4)
      GO TO 4
      END

```

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